Security & Privacy

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Course materials:

https://down.dsg.cs.tcd.ie/cs7053/

https://github.com/sftcd/cs7053

Slideware + some papers

Computer Security Concepts

Introduction of some basic concepts and terminology in computer security

Next while…

- A bit of history…
- Application layer security
- Security evaluation
- Network security
- Identification & Authentication

Computer Security Goals

Traditional Security Goals: "CIA"

- Confidentiality
  - Keeping secrets
- Integrity
  - Preventing unauthorised modifications
  - Keeping data consistent
- Authentication/Assurance/Availability
  - The meaning of the “A” depends upon who you ask!

Services and mechanisms

- From the old “OSI” world, we've inherited two (sometimes confusing, but useful) concepts:
  - Security service: provides a security function to the system, based on the use of security mechanisms, e.g. confidentiality
  - Security mechanism is a technique, or protocol etc. which can be used to provide a service, e.g. encryption, access control

Services/Mechanisms

- Confidentiality
  - Access control
  - Cryptography
  - Secure communication channels
- Integrity
  - Checksums
  - Digital signatures
  - Secure communication channels
- Availability
  - Designing secure software and communication protocols
  - Load balancing
  - Anti-DDoS services E.g. CloudFlare

Structure of Military Security

- Information is classified according to national security
- The classification is clearly labelled on the binder
- All classified information is stored in a safe
- All users are “cleared” to see information up to a certain level
- Users have to prove their clearance to withdraw the binder from the safe
- Additional compartments enforce the *need-to-know* principle

Creating New Information

- New files are labelled with the classification of the most secret component
- Aggregation of unclassified information may generate a “top secret” file
- Sanitization downgrades the label of existing information

Releasing a document downgrades the existing label, but no one ever wants to do that in case they get in trouble.
Leads to increasing number of labels as time progresses with more documents.

Effects of Automation

- Simplifies copying, editing, distribution and reading of documents
- Active tools are used in above tasks
  - Trojan horses
  - Trapdoors
  - Leaking information
- Labelling information is difficult (no stamp)

Old Problems Aggravated

- Aggregation
  - it is easier to aggregate information from a vast set of information
- Authentication
  - it is more difficult for a computer to identify a person (partly solved)
- Browsing
  - it is easier to read all files in a file system than all files in a safe
- Integrity
  - modification is harder to detect (mostly solved)
- Copying
  - digital copies are indistinguishable from the originals (really there are no originals at all!)
- Denial of Service
  - denial of service is a notorious characteristic of computer systems

Multilevel Secure Systems

- The “Holy Grail” in military security
- Separate users with different clearance levels on the same computer system
- Access control is mandatory (policy is defined and enforced by the system) as opposed to discretionary (policy is defined by the user)

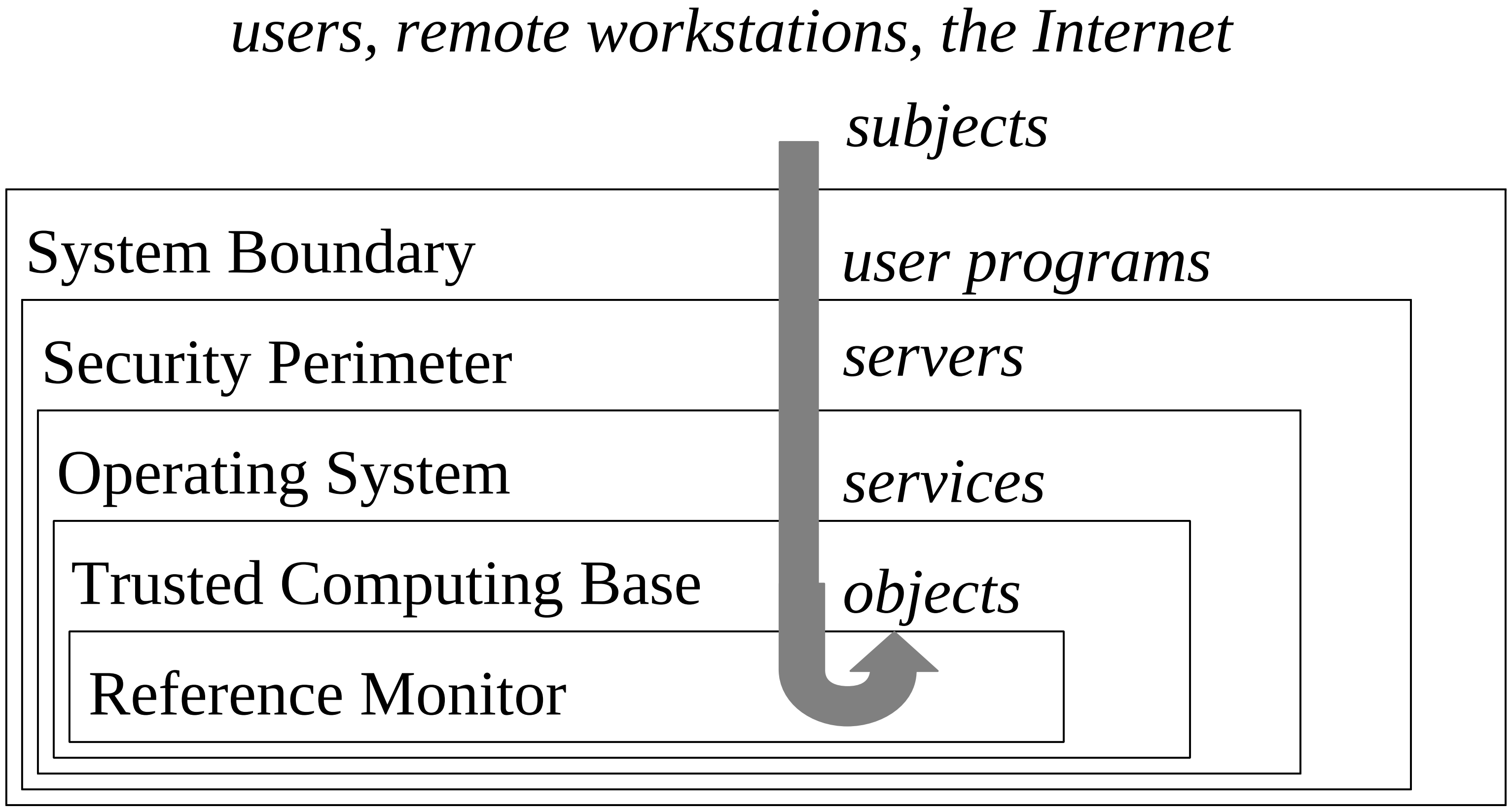
Confinement/Isolation

- Isolate the running process with the minimal set of access rights needed to complete its task (principle of least privilege)
- Control all communication channels:
  - Storage Channels
    - communication through persistent storage
  - Legitimate Communication Channels
    - message passing, RPC, RMI, …
    - Cut'n'paste

Covert/Side-Channels

- Hidden means of communication, that allows information to be leaked to third parties
- Some types:
  - Timing Channels
    - observable differences in system utilization
  - Inference Channels
    - intersection of non-classified information
  - Others?
- Side-channels are like covert channels but often "accidental" ones giving rise to surprising vulnerabilities

Security Perimeters



Attack Surface

- Intuition: more possible ways in which attacks can be attempted => more likely an attack may succeed
  - Listener on a port, Callable API, Command line arguments,...
- Think of the potential attack points as if they formed a geometric construct: the attack surface
  - Smaller attack surface == better! (probably)
  - Useful relative metric as you evolve a system
  - Argues (to an extent) against over-generic tools/re-use (e.g. Content Management Systems (CMS) for web sites perhaps)
- Dec 2018 survey paper (paywall):
  - https://doi.org/10.1016/j.infsof.2018.07.008
- OWASP guidance:
  - https://www.owasp.org/index.php/Attack_Surface_Analysis_Cheat_Sheet
- Michael Howard (msft) concept from 2003:
  - https://docs.microsoft.com/en-us/previous-versions/ms972812(v=msdn.10)

Attack Surface Examples

- Hardware Security Module (HSM)
  - IBM 4758 CCA v2.5
  - Nice 2005 attack by Ross Anderson, Ron Rivest, et al: “A Note on EMV Secure Messaging in the IBM 4758 CCA”
    - https://www.cl.cam.ac.uk/~rja14/Papers/CCA-EMV.pdf
- Any computer running useless services
- Any computer without a local firewall

Sidebar: Operating Systems

- We won't cover OSes or virtualisation much as issues are very system dependent
  - UNIXes, incl. GNU/Linux distros, OpenWRT, Apple iOS/macOS, Android/AOSP, flavours of busybox with Linux kernel, Windows, Cisco IOS, JunOS,...
- Basic idea is to isolate processes (users are represented as processes) and privileges
- Cross-boundary vulns have most impact
- Local privilege escalation (LPE); by itself: mostly meh!
- Remote code execution (RCE) or break out of VM/browser sandbox: BIG deal!
  - * – RCE + LPE = yay! (for attacker) *
- Recent work on side-channels (spectre/meltdown etc.) tells us speed and security trade-offs have been mismanaged in many environments for many years

Don't prioritise optimisation over security.

Commercial Security

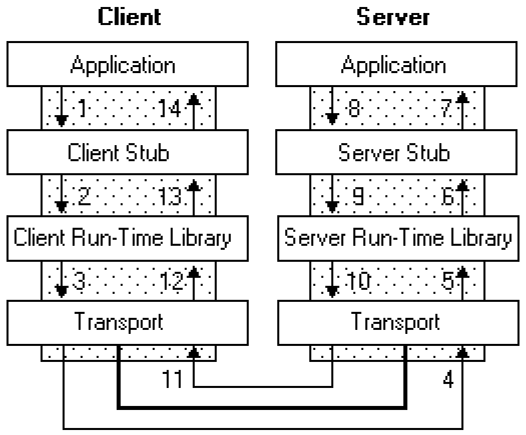
- Historically the military paid more for security, were more accepting of the inconvenience (which almost all security mechanisms introduce), and had a chain-of-command upon which to fall back
- Co-operating/competing commercial enterprises have none of these

Typical Enterprise Security Model (circa 1995)

- System and network administrators setup and manage users and applications
- Distributed Computing Environment (DCE) exemplifies this approach
- Authentication spec (needs a login;-():
  - https://publications.opengroup.org/c311
- Some code:
  - https://github.com/dcerpc/dcerpc
- Kerberos v5 (RFC4120) – still persists as part of MSFT windows and a few other systems

DCE RPC Model

- Server has function f(a,b); client wants to call
- Interface definition language (IDL) used to generate client and server “stubs” f_client(a,b) and f_server(a,b)
- Run-time hides transport from client
- Client call to f(a,b) goes around the world
- Transport does security stuff (via GSS-API in the case of DCE RPC)
- Diagram from:
  - https://docs.microsoft.com/en-us/windows/win32/rpc/how-rpc-works
- Diagram doesn’t show Kerberos server(s)



Problems with the 1990's enterprise security model

- Generally assumed a homogeneous network and set of applications

  Merged networks and systems break this assumption
  - Became more false as time went on
- Assumption that all users and applications were centrally managed
- Deployment showed up performance and usability issues

Security APIs

- Periodically someone tries to develop an API to “hide” security
- Has worked fine for cryptographic primitives
  - MS-CAPI, PKCS#11, JCE, NaCL, …
  - Pretty much all good development tools and environments have some cryptographic API (python, PHP, …)
  - Some recent API issues with post-quantum cryptographic algorithms (more later)
- Not so successful for higher layer security functions
  - Main generic API attempts: GSS-API, SPKM

Sidebar: Crypto makes interop harder

- It is **much** easier to get a system to (supposedly) "work" in "insecure" mode
  - And **much, much** easier if "secure" mode involves cryptography
- This is a general problem which has lead many people to turn off/down security
- * Answer: develop with crypto turned on *
- Bear it in mind as you design things

Encrypting data makes developing a system harder because of the added cryptographic functionality

But it is crucial and must not be left out.

Along came the web

- The number of reachable hosts rose exponentially for a while
- Highlighted security issues with:
  - Proxies (various bad things can happen at a proxy)
  - Tunnelling ("protocol-X" over HTTP)
  - Having a ubiquitous tunnel end-point on many machines
  - Browser security models

Security Evaluation and Network security

Customers need some confidence that the system or network that they are about to purchase is “secure”.

Security Evaluation Criteria

[TCSEC] Department of Defence Trusted Computer Systems Evaluation Criteria (Orange Book) - 1985
https://csrc.nist.gov/publications/secpubs/rainbow/

[ITSEC] IT Security (UK, NL, FR, DE) - 1991
https://www.bsi.bund.de/SharedDocs/Downloads/DE/BSI/Zertifizierung/ITSicherheitskriterien/itsec-en_pdf.pdf?__blob=publicationFile

[Others] CTCPEC (Canada) JCSEC (Japan)

[CC] Common Criteria (ISO IS 15408) – 2022

https://www.commoncriteriaportal.org/files/ccfiles/CC2022PART1R1.pdf

Security Evaluation

- How do we compare the security of different computer systems?
  - Different authentication mechanisms
    - Kerberos, passwords, smart cards, …
  - Different access control mechanisms
    - Access Control Lists, Role-Based Access Control, …
  - Different cryptographic algorithms
    - DES, AES, RSA, ECC, D-H, Curve25519…

“Orange Book” Classification

Class	Title	Key Features
A1	Verified Design	Formal top-level specification and verification, formal covert channel analysis, informal code correspondence demonstration
B3	Security Domains	Reference monitor (security kernel), “highly resistant to penetration
B2	Structured Protection	Formal model, covert channels constrained, security oriented architecture, “relatively resistant to penetration”
B1	Labeled Security Protection	Mandatory access controls, security labeling, removal of security related flaws
C2	Controlled Access Protection	Individual accountability (authentication) and extensive auditing
C1	Discretionary Security Protection	Discretionary access controls, protection against accidents among cooperating users
D	Minimal Protection	Not Classified

ITSEC

- Separation of functionality and assurance
- Functionality-classes (F-C1 – F-B3) corresponds to the Orange Book
- Assurance-classes (E0 – E6)
  - E0: lowest, E6 highest
  - E4: commonest (maybe)
- Target of Evaluation
  - Set of evaluated components: security policy, security related functions, definition of the required security mechanisms for the target level of evaluation

Common Criteria

- Combines previous criteria
  - Separation of functionality and assurance
  - Target of Evaluation (TOE)
  - Security Target (ST) = desired level of evaluation
- Protection Profiles (PP)
  - Security Requirements
  - Security objectives
  - Independent of Implementation

Other aspects of assurance

- Installation and use must be considered
  - What are the defined security policies?
  - How is the software installed?
  - How are the machines administered?
- Development tools & environments
  - SNMP exploit due to buggy 3rd party ASN.1 handling library

Assurance != "Works-as-advertised”

- Assurance only shows that the product/system matches a specification
  - NOT that it does what the customer wants!
- The product owner pays the evaluator (lots!!)
  - So although the evaluator is Government licensed, they have reasons to be nice to the developer.
- Caveat emptor rules ok.

Network security

- Different from application layer security
  - Usually no real interest in APIs here
  - Normally trying to secure either a (sub)network, or network node from network based attacks
  - Frequently network nodes don't use standard operating systems
    - E.g. Cisco routers, 802.11 access points

Network Security

- First, read about networks, you need to have some level of understanding of IP (both), DNS, TCP, BGP, HTTP and how e.g. Javascript/PHP works on the web
  - Go find your own URLs:-) Or a book.
- I expect you'll do this yourself or have gotten it from other modules from this or other years' study
- Some good network security reading starters:
  - https://www.sans.org/ training stuff etc.
    - https://isc.sans.edu/ "Internet Weather"
  - https://first.org/library/ more reading
  - https://www.owasp.org/ web security

Open source intelligence OSINT

MISP - Malware Information Sharing Platform and Threat Sharing

https://www.misp-project.org/

https://github.com/MISP

Idea is to share information about attacks and indicators of compromise (IoCs)

Some events shared openly, some less so

Not clear (to me) how often these resources are updated

You can browse some JSON at https://www.botvrij.eu/data/feed-osint/

- Interestingly the 2nd file there related to the HSE ransomware attack:

  https://www.botvrij.eu/data/feed-osint/02a470d8-493e-41d9-8367-622460dddbe8.json

Learn from networks you use...

- Browser developer UI to see HTTP/JS
  - network/JS/console: “shift-ctrl-I” or similar
- Wireshark/tshark/tcpdump to see packets
  - Wireshark dissectors exist for many protocols, DNS, TLS, ...
- Protocol capture (PCAP) files
  - Careful of privacy – PCAPs can be revealing and are hard to anonymise
  - Please tell me if you know of good up-to-date PCAP anonymisation tools!
- If this is new to you - **do play with these** – you’ll learn stuff!

Network security view

- Original Internet “architecture” assumed end-to-end connectivity
- Hence end-to-end security was the main consideration for those developing the Internet
  - But they were **very** slow developing IPsec (about 10 years!)
  - And meanwhile NAT and firewalls arrived

The End-to-End Argument

Saltzer, Jerome H., David P. Reed, and David D. Clark. "End-to-end arguments in system design." ACM Transactions on Computer Systems (TOCS) 2.4 (1984): 277-288.

https://cct.lsu.edu/~kosar/csc7700-fall06/papers/Saltzer84.pdf READ THAT!!!

And then *RFCs 1958 & 3439*

And *RFC 7258* (why not:-) and even *RFC 8890*

- caution, co-author of that 2nd-last one present:-)

E2E Argument has current consequences...

HTTP/2, QUIC and h3 are protocols that attempt to have e2e encryption as a mandatory(ish) mechanism not (only) in order to achieve a confidentiality service but primarily to mitigate ossification

Some, but not all, of those who know what’s going on are happy with that

FWIW, (which is not much) I am happy with that.

Network Address Translation (NAT)

- NAT is today mainly used to hide local addresses from the Internet for (mostly) provisioning reasons
  - NAT means that the higher layer end-points “see” different addresses for one another
  - Breaks many end-to-end assumptions
- “Carrier Grade” NAT (CGN) is coming to an ISP near you soon (or has already)

CGN & Security

- Many more endpoints behind each public IPv4 address; put a NAT box in the ISP network
  - NAT444
  - There are other, maybe better, IPv6 transition mechanisms
  - Some think this is an IPv6 avoidance mechanism
- Good way to freak out “legal intercept” (LI) fans
  - LI+CGN: Good way to freak out ISPs who have to log
- Good way to freak out anyone who wants to offer a public service
  - PITA for DNSSEC
- Bad way to get to an IPv6 world?
  - But may be needed for some time

NAT problems with SIP

```
UserA      NAT                          NS          UserB
   10.1.1.221  192.168.221.1  63.88.221.88  192.168.1.10
   |                  |             |             |
   |----F1 INVITE---->|--F2 INVITE->|             |
   |                  |             |--F5 INVITE->|
   |<---F4 100--------|<-F3 100-----|             |
   |                  |             |             |
   |                  |             |<--F6 180----|
   |<---F8 180--------|<-F7 180-----|             |
   |                  |             |             |
   |                  |             |<--F9 200 OK-|
   |<---F11 200 OK----|<-F10 200 OK-|             |
   |                  |             |             |
   |----F12 ACK------>|---F13 ACK---|             |
   |                  |             |--F14 ACK--->|
   |                  |             |             |
   |<---F15 2WAY RTP->|<-------F16 2WAY RTP------>|
   |                  |             |             |
   |----F17 BYE------>|-F18 BYE---->|             |
   |                  |             |--F19 BYE--->|
   |                  |             |             |
   |                  |             |<-F20 200 OK-|
   |<---F22 200 OK----|<-F21 200 OK-|             |
   |                  |             |             |
```

Virtual private networks (VPNs)

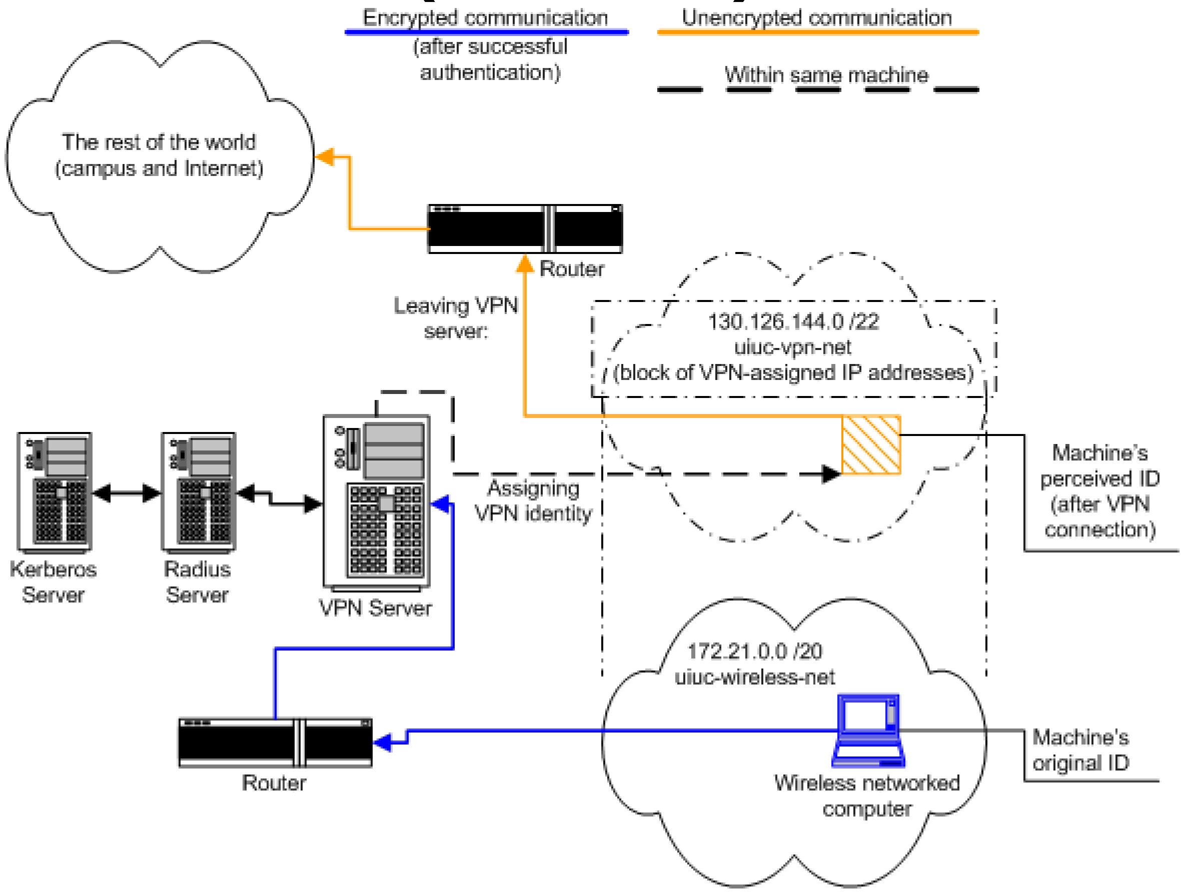

Encrypted communication (after successful authentication)
Unencrypted communication
Within same machine
The rest of the world (campus and Internet)
Router
Leaving VPN server:
130.126.144.0 /22
uiuc-vpn-net
(block of VPN-assigned IP addresses)
Machine's perceived ID (after VPN connection)
Assigning VPN identity
Kerberos Server
Radius Server
VPN Server
172.21.0.0 /20
uiuc-wireless-net
Router
Wireless networked computer
Machine's original ID

Diagram from https://www.cites.illinois.edu/vpn/vpnnetdiagram.html I used to say to go there for a detailed explanation, but bitrot has got that URL, there's a similar one at https://answers.uillinois.edu/illinois/page.php?id=47631 (for now:-)

Firewalls

- Until the mid-90's most sites didn't bother filtering traffic
- It became clear that exposing your internal network topology could cause problems
  - E.g. If I know that router brand "X" has an open default configuration and I can see that you've got one of those, then my attack point is clear

Filtering routers

- Initially people put in filtering rules in border routers
  - E.g. “no packets with a destination on my inner network are allowed out”
- But, IP spoofing attacks meant that this wasn't sufficient
  - So firewall products developed
  - Note: has been biggest security product market, but I've not checked recently

Denial-of-Service (DoS)

- Consume resources to make a service unavailable
  - Has been known as a vulnerability for many years
  - Began to be exploited around turn of century on major Internet sites
  - And then on other infrastructure: DDoS attacks against DNS root servers
- DDoS = Distributed Denial of Service

TCP SYN flooding attack

- SYN packets with spoofed IP addresses cause the server to maintain state
- Flooding the server that way is your basic DoS attack
- US Computer Emergency Response Team (CERT) was established in the wake of the ‘88 worm
- US-CERT issues advisories about vulnerabilities like this:
  - https://www.cisa.gov/news-events/cybersecurity-advisories
  - CERT Advisory CA-96.21 https://seclists.org/bugtraq/1996/Sep/61

Network access protocols

- Issue is how to decide when to allow a node to join/use the network
  - IEEE 802.1X networks (eduroam)
  - Corporate networks
  - Mobile operator networks
- RADIUS protocol (or Diameter)
  - RFC 2865 (or RFC 6733)

Search Engines

- ...to find vulnerable systems
- Shodan HQ https://www.shodan.io/
  - Est. 2013 - search for “camera”
- Censys https://search.censys.io
  - Mainly IPv4 based surveying (zmap)
- Ichidan ichidanv34wrx7m7.onion
  - Was a “Dark web” search engine, over .onion services
  - Didn’t work for me, even in 2017, and seems to have gone away sometime in 2018
- There are more I guess...

Censorship Circumvention

- Onion routing https://www.torproject.org/
- Tor Browser: https://www.torproject.org/projects/torbrowser.html.en
- Tor Hidden services: “<hash>.onion” DNS-like names
- Search engine for those: https://ahmia.fi/
- Tor snowflake – uses WebRTC data channel: https://gitlab.torproject.org/tpo/anti-censorship/pluggable-transports/snowflake/-/wikis/home
- Geph, psiphon, other VPNs
- There are projects that measure blocking e.g. OONI
- https://explorer.ooni.org/chart/circumvention?since=2022-12-31&until=2023-01-31&probe_cc=CN%2CIR%2CRU
- **Be careful** though! In some places being found with such apps on your phone can lead to **arrest**

My browser setup (2025)

- Tor Browser: If searching for something sensitive (e.g. medical info)
- Search default: Brave search (Where “!g” works too:-)
- Default browser: FF nightly + NoScript/Ghostery & disallowing cookies, with some allow-listed sites
- Some sites don’t work with the above; mostly: screw ‘em
- For TCD stuff: brave
- For home n/w admin: opera
- For github/gitlab: vivaldi
- If-need-be: chromium/incognito with a chmod of $HOME/.config/chromium to make almost all read-only (but not sure of effectiveness)
- On (de-Google’d android) phone: Brave with “shields” up and FF nightly as 2ndary open-kimono browser
- Recommend you figure out some browser-hygiene you prefer and implement that – be willing to help others do the same!

Advertising and RTB

- For more on privacy, advertising and real-time bidding (RTB), see the “what is the Internet doing to me” (witidtm) module materials
  - https://down.dsg.cs.tcd.ie/witidtm/
- In particular, RTB is covered in:
  - https://down.dsg.cs.tcd.ie/witidtm/lectures/2023-2024/800-ads.pdf
- The Irish Council for Civil Liberties (ICCL) are also doing good work in this space:
  - https://www.iccl.ie/rtb/
- The above is (IMO) a good reason to want good browser hygiene but also to minimise the mobile apps you use

Biometrics

- Many people (apparently) think that replacing username & password with a biometric is a great idea.
- It might be:
  - If secure biometrics exist
  - If the re-use implications are acceptable
  - If the context supports the full life-cycle

Identification

- Establish the identity of principals by means of:
  - something known (*password, PIN*)
    - Separate slide deck
  - something possessed (*smart card, Java ring*)
  - something personal (*fingerprint, retina scan*)
  - something to do (*signature*)
- Combinations of above (*smart card + PIN*)

Biometric methods

- Fingerprint
- Retina scan
- Face recognition
- Gait (walking)
- Toe-smell

Fingerprint

- Prof. Tsutomu Matsumota's well publicisied 2002 attack against most common fingerprint recognition engines
  - https://cryptome.org/gummy.htm
  - Information here is directly from his paper: “Impact of Artificial "Gummy" Fingers on Fingerprint Systems”

Fingerprint scanner

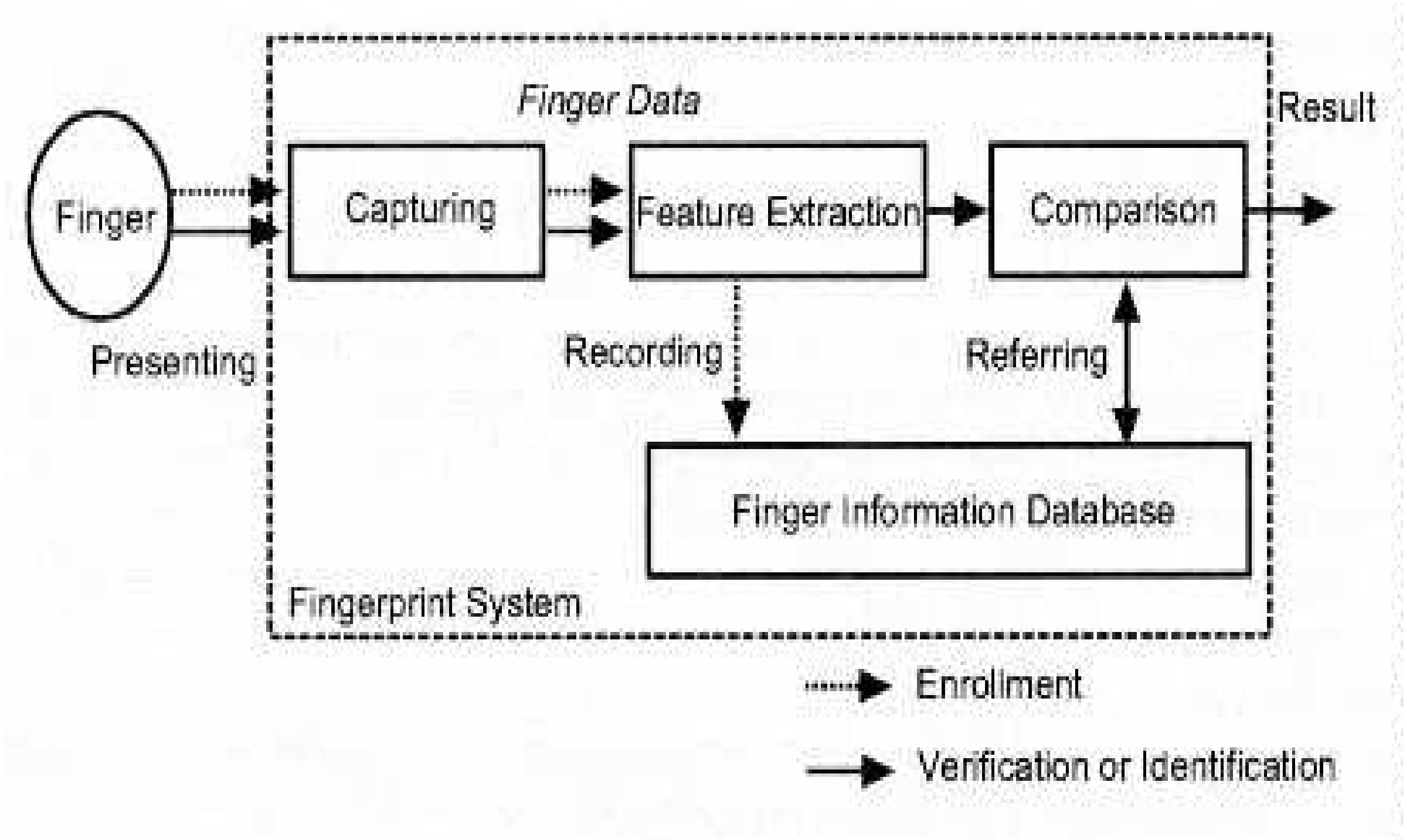
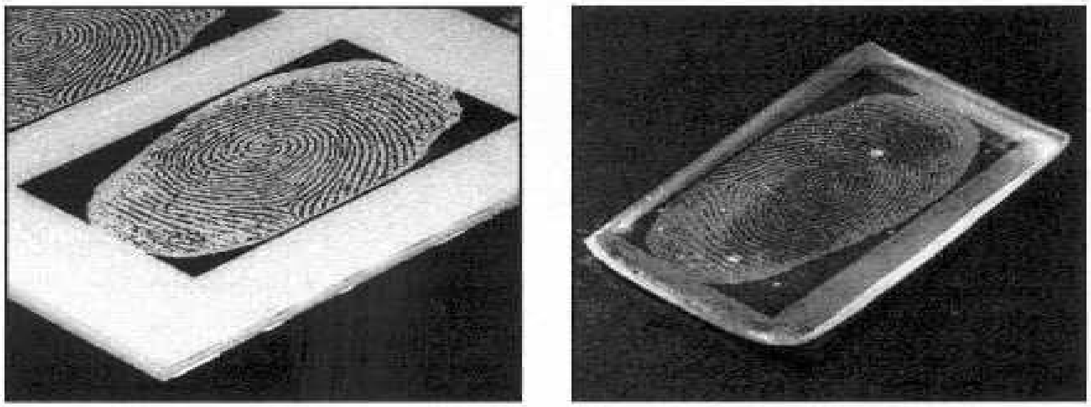


Figure 2.1 Typical structure of a fingerprint system

Make a gummy finger



(a) The mold for gummy fingers (b) Gummy finger

Figure 4.5 Photographs of the outside appearance of the mold and a *gummy* finger. The *gummy* finger was produced from a residual fingerprint on a glass plate, enhancing it with a cyanoacrylate adhesive

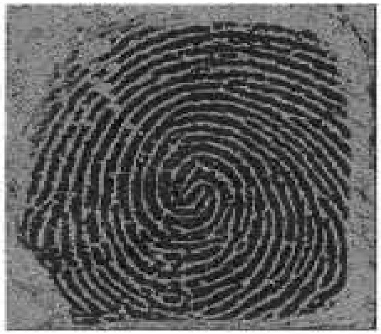


Figure 4.6 The Fingerprint image of the *gummy* finger, which was displayed by the system with Device H (equipped with a capacitive sensor).

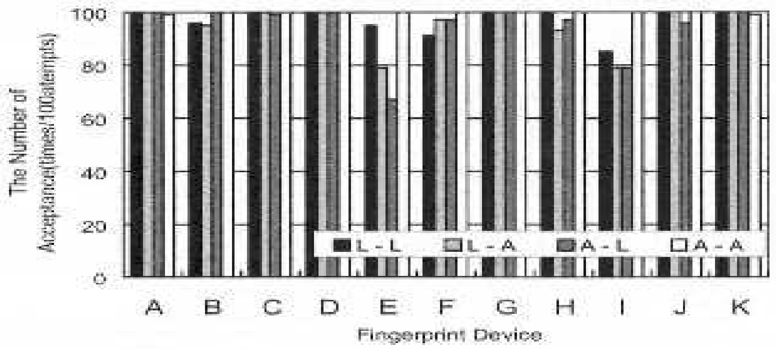


Figure 4.7 Average number of acceptance for each device, in terms of *gummy* fingers which were cloned from residual fingerprints. Here, the subject is one person.

Results

- 11 of 11 scanners tested were broken
  - The list was extended a bit more since
- That's enough of a result!

But there’s more! …

- CCC 2017: 55 minute video of breaking biometrics
    - https://www.youtube.com/watch?annotation_id=annotation_2684251971&feature=iv&src_vid=pIY6k4gvQsY&v=VVxL9ymiyAU
- Fiebig, Tobias, Jan Krissler, and Ronny Hänsch. "Security Impact of High Resolution Smartphone Cameras." WOOT. 2014.
    - https://www.usenix.org/system/files/conference/woot14/woot14-fiebig.pdf
- Roy, Aditi, Nasir Memon, and Arun Ross. "Masterprint: Exploring the vulnerability of partial fingerprint-based authentication systems." IEEE Transactions on Information Forensics and Security 12.9 (2017): 2013-2025.
    - https://ieeexplore.ieee.org/ielaam/10206/7948894/7893784-aam.pdf
- Dürmuth, Markus, David Oswald, and Niklas Pastewka. "Side-channel attacks on fingerprint matching algorithms." Proceedings of the 6th International Workshop on Trustworthy Embedded Devices. 2016.
    - https://dl.acm.org/doi/pdf/10.1145/2995289.2995294

When are biometrics ok?

- What applications?
  - What type(s) of biometric?
  - What benefits?
  - What costs?
    - Financial and other (e.g. Privacy)

What is your #1 mitigation for all problems?

What is your #1 mitigation for all problems?

Yes, Backup.

Do that. Early and often.

Summary

- Services vs. Mechanisms, CIA
- Common Criteria
- N/W security a bit different from system security
- Firewalls etc.
- Biometrics (yuk:-)
- Do backups