Cryptography Session: "How Crypto Gets Broken (by YOU)" 0x74776f616e646168616c66686f7572732121th Ed.

CyberTruck Challenge™ 2023

About Me

linkedin.com/in/Ben0L0Gardiner

github.com/BenGardiner

@BenLGardiner

- **Ben Gardiner**
  - Senior Cybersecurity Research Engineer contractor 🎉at NMFTA 🎉
  - Experience: Embedded systems dev, RE
  - CyberTruck™ Challenge Instructor
  - DC HHV & CHV volunteer
  - SAE volunteer

Thanks to:

@Sagefault + @KennethSalt + Dr. Jeremy Daily

And the *CyberTruck Challenge*™ Event

previously presented at:

CyberTruck Challenge™ 2018-2022 / HF2020 & 2021 / NorthSec 2021

Agenda

- We will **break regularly** for questions at section breaks
  - But also feel free to ask questions anytime
- Much material from the following reference:
  Anderson, Ross. *Security engineering*. John Wiley & Sons, 2008.
  - Buy this book!
  - Prev. editions are also free! www.cl.cam.ac.uk/~rja14/book.html

Challenge: Decrypt 'Crypto'	10
Building Blocks	20
Challenge: Break Hashes	10
↘Attacking Building Blocks	10
Challenges: Break Crypto, others	35📈
Protocols	15
↘Attacking Protocols	10
Protocol: WPA2 (↘ Attacks)	5📈
Protocol: TLS / SSL (↘ Attacks)	20📈
Protocol: UDS Seed-Key Exchange (↘ Attacks)	10
Challenge: Derive the UDS Routines	5
	150 mins

Lightly Compressed. See 2021 UNABRIDGED for follow-up details

‘Crypto’

Cryptography but in orange
Cryptography
THINGS "CRYPTO" MEANS

Crypto Building Blocks

Encryption

- Encryption – an encoding which can be reversed (given a key)
  - A plaintext (M) message is encrypted by a cipher ({}) to a ciphertext (E) using a key (K)

$$E = \{M\}_K$$

  - Decryption is possible with the cipher, the ciphertext, **and the key**
  - e.g. **AES**, **RSA**, **ECC**, **3DES**, …

  - Something that's not encryption: **base64** (e.g. `ZS5nLiB0aGlzIGJhbG9uZXkgcmlnaHQgaGVyZQ==`)

Hands-On: 10 Minute Challenge

'Decrypt' these (you're actually decoding):

- `d2VsY29tZSB0byBIRjIwMjA=`
- `c2VudGluZWw=`

These are base64 encoded (not encrypted).

This might seem obvious to some – but it is not uncommon to encounter base64 'encryption' in the wild.

Here's a handy set of tools for this:
https://web.archive.org/web/2021/http://rumkin.com/
Also python/jupyter: `import base64; base64.b64decode('xxx')`

Hashes

- (Cryptographic) Hashes – not an encoding & not reversible
- Different than the larger, general class of hash functions
- For a crypto. hash function *f*: given *f*(x) you can't find (guess or calculate) **x**

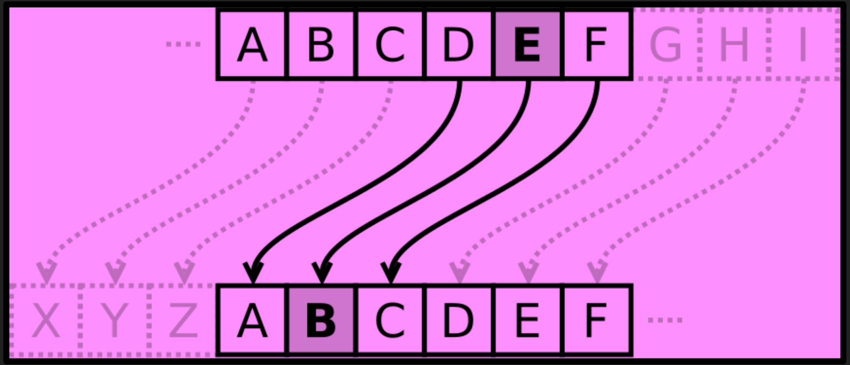
- i.e. shouldn't be able to find input **x** for: `3947cdf52a551de4983746545a1affdb2b04f4a2` or `21232f297a57a5a743894a0e4a801fc3` (actually, this one is easy)

  - aka *One-way Functions*

- aka *Random Functions*
- aka *Shortcut Functions*
- aka *One-way Compression Functions*
- *aka Digests*

- e.g. **SHA-1, SHA-256, BLAKE, …**
- not a cryptographic hash: **MD5**

'Classic' vs Modern Crypto



* Matt_Crypto, wikipedia, Public Domain

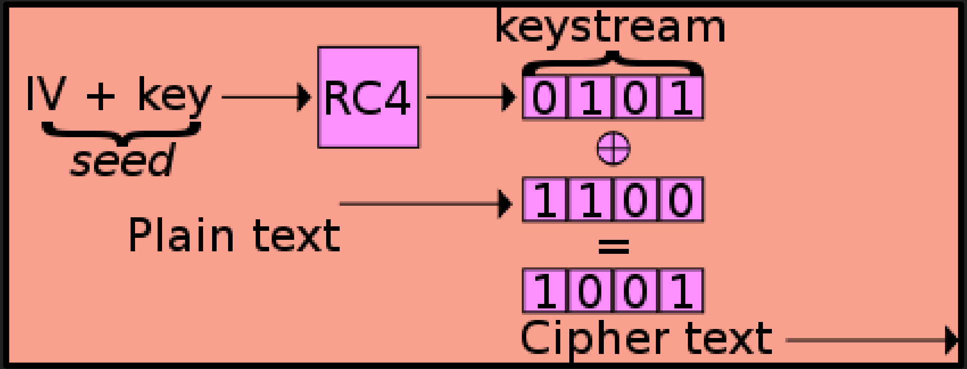
- 'Classic' Crypto
  - Mostly pre-20th century
  - Deals with alphabets: input & output
  - e.g. shift cipher (Cesar cipher)

    AB CD AB CD AB CD … AB CD AB CD AB CD `qbag qrpvcure guvf`
  - e.g. substitution cipher, polyalphabetic substitutions, transpositions etc.
  - It is still encryption – the 'key' is the knowledge of the mapping (shift, letter-map etc.)
  - Relevance today: puzzles, challenges and *easy reverse engineering*

- Modern Crypto
  - Deals with numbers: input & output
  - Text is treated as numbers via encodings – ASCII or UTF-8 is the most likely encoding
    e.g.
    `646f6e7420646563697068657220746869 73 ⊕ (00…10) ➞`
    `646e6c7724616364 6179626e7e2d7a677962`

Stream Ciphers

- One-Time Pad (OTP) – the only *proven secure* encryption scheme
  - Uses random key-stream, of length equal to or greater than the message
  - Then combine key-stream with message (assume XOR)
- Stream Ciphers – approximate the OTP
  - Expand short key into pseudo-random keystream
  - Then XOR (⊕) (^)
  - e.g. RC4, Salsa20, FISH

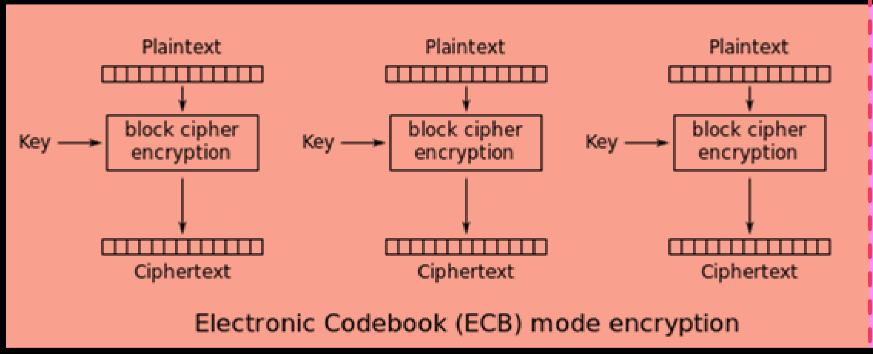


Di Kyle Siehl - Self-made, based on raster w:Image:Wep-crypt.png, which was taken with permission from The Final Nail in WEPs Coffin, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1806804

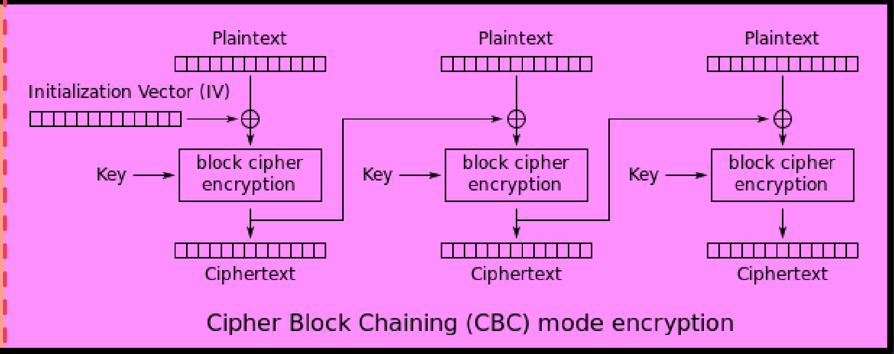
- note: IV – initialization vector. It shouldn't need to be secret

Block Ciphers

- Block Ciphers – different approach
  - Uses a key and fixed-length inputs (blocks)
  - Combined with previous outputs and more fixed-length inputs in various modes:
  - ECB, CBC, PCBC, CFB, OFB, CTR … GCM(!)



By WhiteTimberwolf (SVG version) - PNG version, Public Domain, https://commons.wikimedia.org/w/index.php?curid=26434116



By WhiteTimberwolf (SVG version) - PNG version, Public Domain, https://commons.wikimedia.org/w/index.php?curid=26434096

Symmetric / Asymmetric Crypto

- Symmetric Crypto – can be encrypted + decrypted by any party with the *SAME* key
  - e.g. any of the crypto we've discussed so far
- Asymmetric Crypto – can be encrypted by any party *for* a specific recipient
  - aka public-key cryptography
  - Leverages certain problems that are hard in one way & easy in the other: prime factorization and discrete logarithms
  - Keys exist as pairs of public & private halves -- *key-pairs*
  - The party with the private key can decrypt & sign (more on signatures later)
  - Any parties with the public key can encrypt & verify
  - e.g. RSA, ECC
  - e.g.

```
 -----BEGIN RSA PRIVATE KEY-----
izfrNTmQLnfsLzi2Wb9xPz2Qj9fQYGgeug3N2MkDuVHwpPcgkhHkJgCQuuvT+qZI
…
```

Crypto Building Blocks
Section Summary

- **Encryption**… it hides information, binds it – protects confidentiality, but not integrity (without additional effort)

$$E = \{M\}_K$$

- (Crypto) **Hashes** – one-way functions. With $f(x)$ you cannot get x
- **'Classic' Crypto –** involves alphabets not numbers
- **Stream Cipher** – combine a sequence of key bits with a sequence of cleartext bits with `XOR (⊕) (^)`
- **Block Ciphers** – have a limited key stream, but extend to larger cleartext sequences
  - Not all block cipher modes are created equal (e.g. Electronic Coloring Book (ECB))
- **Symmetric Crypto** – all parties share the same key
- **Asymmetric Crypto** – only one party has the decryption key (private key)

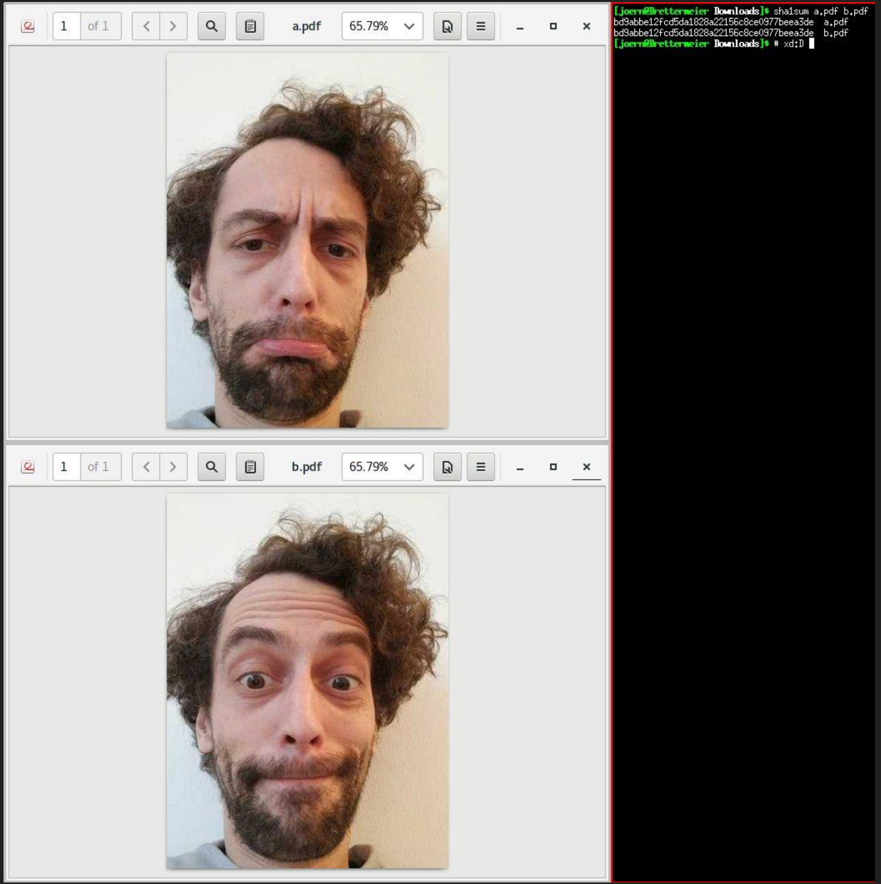
Attacks on Building Blocks

Attacking Hashes

- Google.
    - *Seriously*… google this `21232f297a57a5a743894a0e4a801fc3` (from before) now
- Identifying what type of hash you have in-hand will be useful – the length gives it away
    - If you don't know lengths yet, use hash detector tools; e.g. `cothan/hashdetector`
- Hash Crack sites
- `hashcat` tool
    - (ab)uses your GPU for rapid hash cracking
- Rainbow Tables
    - 'halves' / parts-of hashes pre-built and ready to go
    - For things like MD5 these are trivial
    - For things like SHA-256 these are huge (multi-TB)
        - You can pick-up pre-generated tables at DEFCON Data Duplication Village. Bring a 6 TiB HDD.
- And cooler things like hash-length extension attacks

Cooler Attacks on Hashes

- Hash-Length Extension Attacks
  - Take a known H('start') and add to it to get: H('start' + junk)
  - Get to a known identical hash for 'start' and 'start' + junk
- Taking Advantage of File Formats
  - PDF has lots of place to hide information
  - See Ange Albertini's work on PDF polyglots
  - This can be leveraged to create PDFs with the same SHA-1
  - https://shattered.io/ 😎

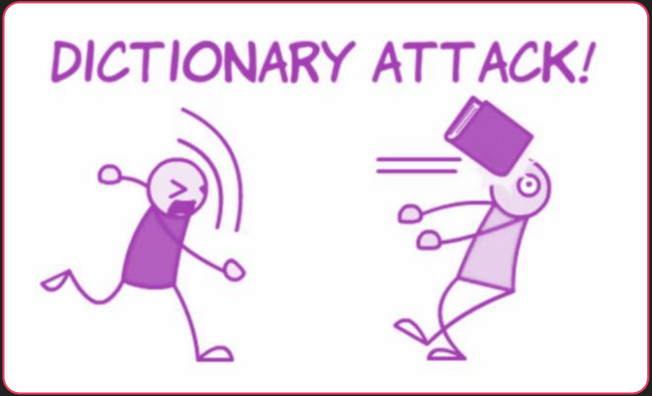


```
[joern@Bretterweier Downloads]$ sha1sum a.pdf b.pdf
bd9abbe12fcd5da1828a22156c8ce0977beea3de  a.pdf
bd9abbe12fcd5da1828a22156c8ce0977beea3de  b.pdf
[joern@Bretterweier Downloads]$ # xd:D
```

More on Attacking Hashes

- Salts
  - Because it’s pretty easy to lookup or build a table of known inputs for hashes; designers tend to follow the best practice of ’salting’ their inputs
    - `D033e22ae348aeb5660fc2140aec35850c4da997 = SHA1(‘admin’)`
    - `3947cdf52a551de4983746545a1affdb2b04f4a2 = SHA1(‘saltadmin’)`
  - Salts are usually pre-prepended onto the input; sometimes with a separator like ‘.’ or ’+’
  - `hashcat` can find a salt for a given hash and input pair.
  - `hashcat` can also find inputs for hashes with a given salt as a parameter.
    - Find the salt with one known hash first.
    - OR find the salt with research (some systems’ password salts are well-known)

Still More on Attacking Hashes



- Password lists
  - Brute-forcing (all possible character combinations) for inputs to hashes is possible
  - 'password lists' are more useful. There are hundreds of these to choose from, most from data breaches over the past years.
  - In CTFs the rockyou list is the most common – but for applied hash cracking: YMMV.
  - This is more generally known as a dictionary attack

Hands On: 10 Minute Challenge

Reverse these hashes:

- ❑ `5f4dcc3b5aa765d61d8327deb882cf99`
- ❑ `5baa61e4c9b93f3f0682250b6cf8331b7ee68fd8`
- ❑ `ecadec2924e86bf88d622ceb0855382d`
- ❑ `ff4827739b75d73e08490b3380163658`
- ❑ `6ce3bb6eb450df7d6345151ec00e4a4e`

We've mentioned the tools you need for this.

Some are *easy*. One is not (hint: 2 character salt)

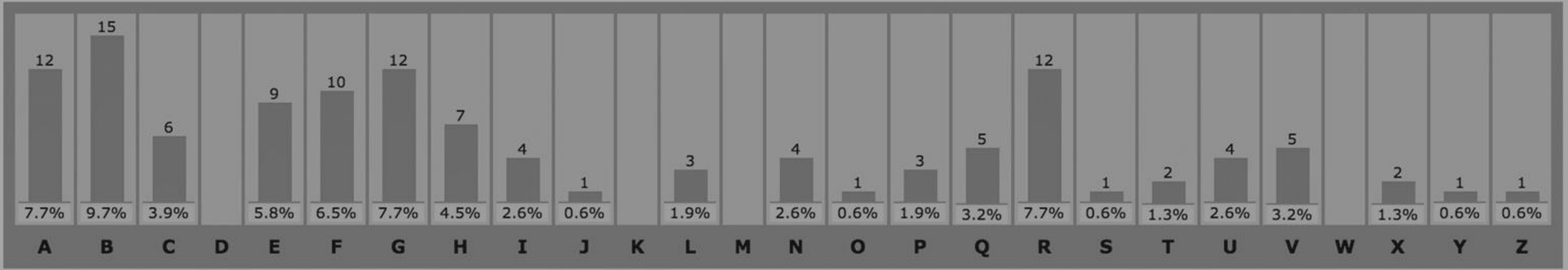
Attacking ‘Classic’ Crypto

- Historically, frequency analysis was the undoing of classic crypto
  - Letter use in a language (e.g. English) has a predictable # occurrences (frequency)
  - Count the number of occurrences of a symbol in ciphertext; match to expected rate in language
  - Requires medium-large ciphertext for analysis to work

- Today (challenges/puzzles/RE):
  - Try shift ciphers (start with ROT13)
  - Then try a substitution cipher
  - Then have ‘fun’ : https://web.archive.org/web/2021/http://rumkin.com/

Hands On: 5 min Classic Crypto Attack Example

Ploregehpx 2018 sbe gur jva!
N uhtr gunax lbh arrqf gb tb bhg gb bhe fcbafbef. Guvf ceb-vaqhfgel rirag qrcraqf ba npgvir fcbafbe vaibyirzrag naq fhccbeg.



Stream Cipher Attacks

- Re-used Key Attack
  - Recall: it's all about XOR (⊕) (^)
  - If I know A^B and I know A or B, I can get the other

  - Anytime a stream cipher re-uses keys, it's a problem
  - if I have E1 = A^K and E2 = B^K I can get A^B

  - this is a big deal if:
    - A, B are natural language (use running key cipher attacks on A^B) or if
    - A, B are different lengths or if
    - we can control A or B or if
    - we can make any guesses about A or B

Hands On: 10 Minute Challenge

Break these stream-ciphertexts

And get the key

- `ad9bc999b790c281`
- `b69895ddecce86cc`

- it’s all about XOR (^)
- [redacted]

Block Cipher Attacks

- Getting impractical now…
- Goals: forgery or key-recovery
- Block Cipher Attack Models
  - **known plaintext**: attacker is given a set of pairs of cleartext+ciphertext
  - **chosen plaintext**: attacker has the ability to query cleartext and receive ciphertext
  - **chosen ciphertext**: attacker has the ability to query ciphertext and receive cleartext
  - **chosen plaintext/ciphertext**: attacker has the ability to query either
  - **related key**: attacker has the ability to query with key related to specified key, K (e.g. K+1 K+2, ...)

Padding Oracle Attacks

- An example chosen ciphertext attack:
- Padding oracle attack: attacker supplies ciphertext, detects ‘incorrect padding’ error conditions – can use this oracle to ultimately decrypt messages
- Surprisingly common

Cryptanalysis and More

- Linear Cryptanalysis
  - solving for linear relationships between cleartext (input) and ciphertext (outputs)
  - at fractional likelihoods
  - using the likelihoods to *sometimes* predict ciphertext from cleartext
  - 'correct' crypto is designed to resist these attacks

- Differential Cryptanalysis
  - solving for sensitivity relationships of changes to cleartext bits (input) onto ciphertext bits (outputs)
  - at fractional likelihoods
  - then use any high likelihoods to guide attacks with chosen inputs
  - Modern ‘correct’ crypto is design to resist these attacks too

- Other Cool Stuff: Slide Attack, XSL Attack, Impossible Differential, Boomerang, ...

Reality Check

- We talked about attack models & attack goals; some families of attacks
- No simple attacks after 'Classic' crypto
- Few practical attacks
- Attacking Crypto *these ways* is hard, for 'correct' crypto:
  - e.g. SHA-256, AES-128, RSA-2048, ECC w/ curve 25519
- For *incorrect* crypto (e.g. anything else)
  - Is it XOR 'Crypto'? → Try XOR ciphertexts together; try XORing it with good guesses too
  - OR Are there repetitions of data patterns in the ciphertext? Maybe it is ECB mode or maybe it is key-reuse in a stream cipher
  - OR If you know the name of the crypto, use google – maybe you will find tool or PoC to break it
- But it's not impossible
  - People build protocols out of these building blocks – protocols get broken more often
  - (and don't forget side-channel attacks and software exploitation)

Hands-On: 10 Minute Challenge

Decipher the following strings:

```
Lqydolg#Sdvvzrug$          Sdvvzrug#RN$$$#=,
```

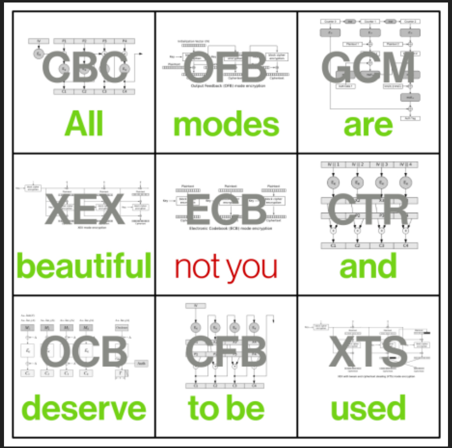
Hints:

- from the IOLI crackme challenges:

  `pof.eslack.org/tmp/IOLI-crackme.tar.gz`

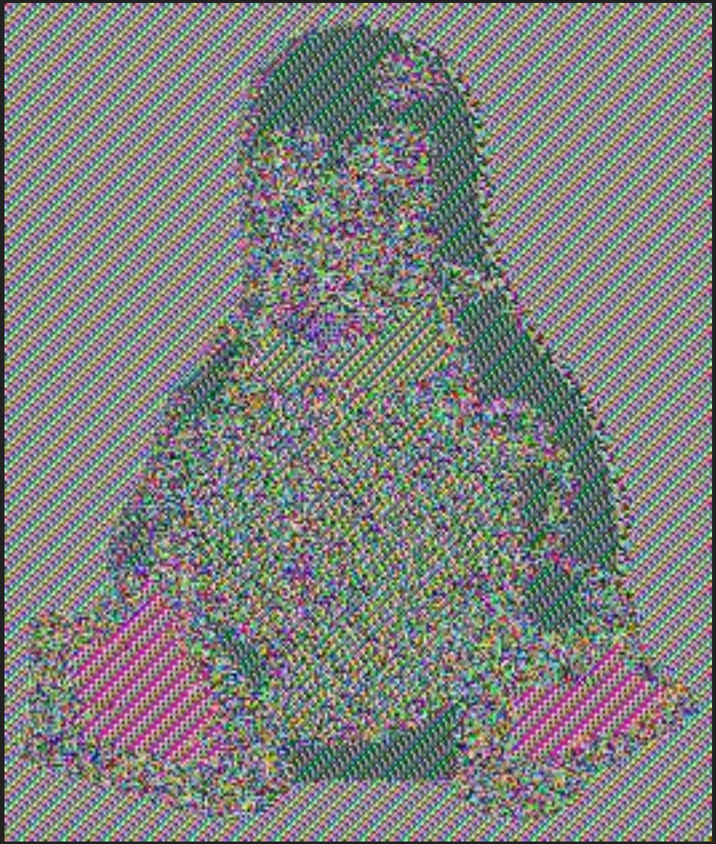
Done? Already? Do a 'beginner' challenge at `potatopla.net/crypto/`

Other Attacks on Block Ciphers



- Recognizing ciphertext blocks can let you decrypt them:
  - maybe not to their contents, but to their meaning
  - (Sometimes also their contents; e.g. infer all-zeroes input)
- Use viz tools: vix, radare2, binvis.io, Veles, hobbits

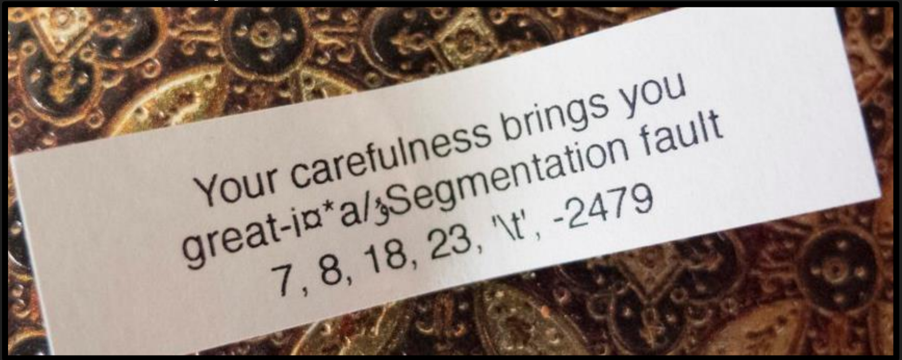
AES_ECB( ) =



https://github.com/pakesson/diy-ecb-penguin

Other Attacking Building Blocks

- Software Exploitation can yield both control of the software and also information leaks


Your carefulness brings you
great-iα*a/ʒSegmentation fault
7, 8, 18, 23, '\t', -2479

  - Access to process memory can be fruitful *key extraction* attacks
  - Multiple tools are available to scour memory for keys:
    - e.g. `aeskeyfind`, `radare2`, `volatility`
  - Reverse engineering of the program code in memory can yield pointers to the memory locations of keys
- Don’t underestimate the downplayed Infoleak vulnerabilities
  - c.f. Heartbleed

Aside: Entropy Visualization

- *Entropy* (in the sense of C. Shannon) is a metric of information-density in message/value/bit-sequence
  - It turns out (thanks also to Shannon) that information is maximized when the likelihood of 1/0 are equal
  - i.e. ‘completely random’ *IS* highest entropy.

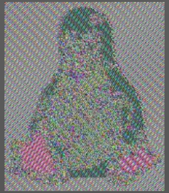
- The entropy of a bitsequence can be estimated
- Estimated entropy approaches 1.0 for random number sequences
  - Next-closest to 1.0 is ‘correct’ crypto
  - Then compressed data
- Estimated entropy is not high for other data (structured data)

Aside: Entropy Visualization (cont'd)

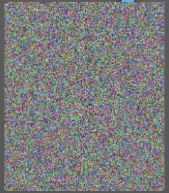
- The entropy estimates can be broken-up over a large input and visualized
- You can identify and distinguish between
  - encrypted (correct) content
  - Other encrypted (incorrect) content
  - Compressed content
- Rules of thumb:
  - Compression looks like pretty high entropy
  - Encryption looks like really high entropy

Aside: Entropy Visualization (cont'd)

Image

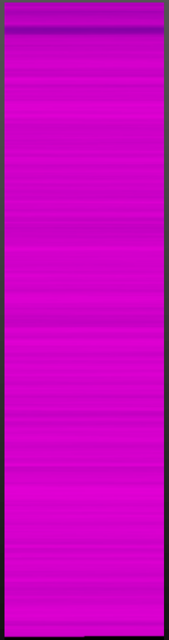


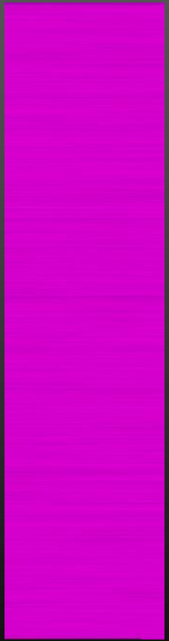
AES ECB

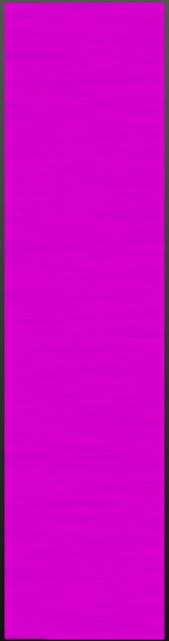


AES CBC

binvis.io
entropy







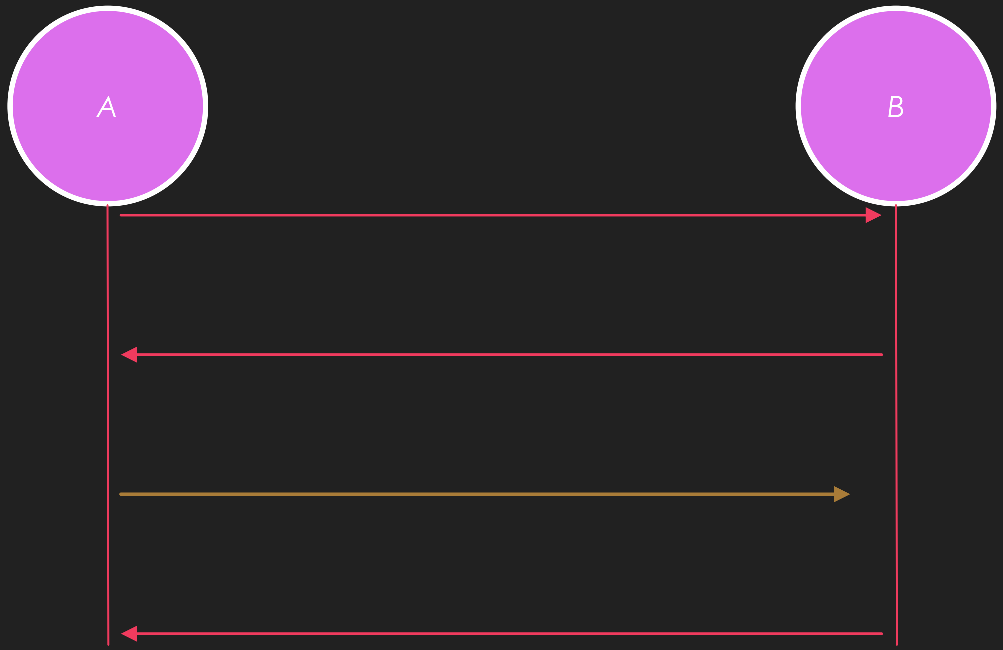
Attacks on Building Blocks Section Summary

- **Hash Attacks** – collisions, pre-image etc. use google. All other practical (for us mortals) attacks are in `hashcat`, use it.
- **Classic Crypto Attacks** – frequency analysis. Try simple things first, use cryptogram tools, ID the cipher and try cipher-specific attacks
- **Stream Cipher Attack** – Reused Key Attack. i.e. try XOR (^) things together, make guesses
- **Block Cipher Attack Models** – probably impractical but use the right search terms
  - Except ECB: recognize patterns
- Don't forget about software exploitation; in-memory attacks.

- Breaking protocols is more fruitful (next sections)
- Remember these tools:
  - https://web.archive.org/web/2021/http://rumkin.com/
  - CyberChef: https://gchq.github.io/CyberChef/
  - Visualization tools: `binwalk -E`, radare2, binvis.io, Veles, hobbits

Protocols

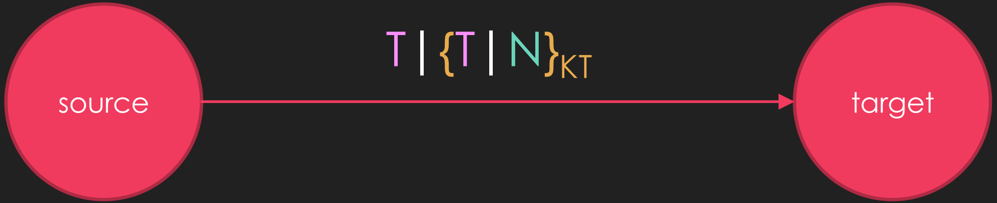
Protocols



- Protocols – the rules that govern the communication between parties
  - What information is transmitted from party A to party B?
  - What steps must party B perform?
  - What information must be sent in reply (if any)?
  - etc.

Protocol: Simple Authentication

- Simple Authentication:
  - Source: wants to be authenticated by the target
  - Target: decides if source is authentic
  - The source sends:
    - its ID (T) plus an encrypted concatenation of T and a nonce (N) , with a key (KT) that could be specific to the ID and also is known to the target.

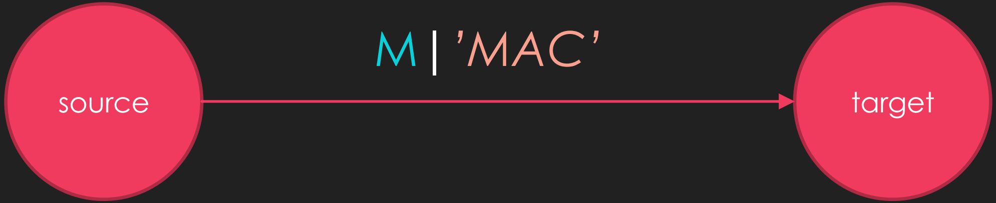


  - The target:
    - looks-up encryption key KT from given ID T;
    - decrypts the $\{\ldots\}_{KT}$ and checks the nonce N hasn't been seen before.
      - Nonce : Number used ONCE

(e.g. older keyfobs / garage door openers – source is the fob, target is the car or garage door.)

Protocol: Message Authentication Codes (MAC)

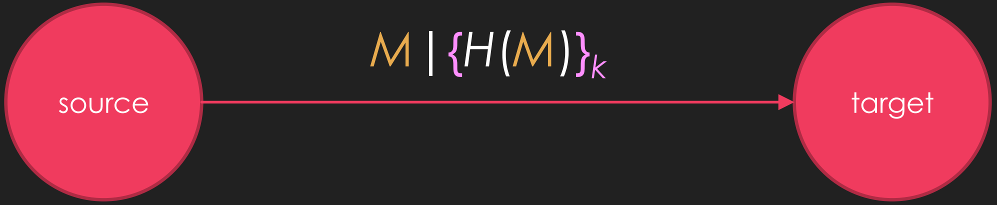
- Message Authentication Codes: for a message, create a value that can enable the message to be verified by any party with the shared key (the same shared key that is used to create the value). e.g.:
- CBC-MAC – build a MAC with CBC chaining mode of a block cipher
- CMAC – also uses a block cipher
- HMAC – build a MAC with a hash function
- CBC-MAC-AES128, HMAC-SHA1, etc.



- Parties receiving messages that don't verify against the key (shared in this case) shall discard messages
  - How the shared keys are distributed and how messages are discarded is additional protocol details (for the next layer of the protocol specification)
- aka *Message Integrity Code (MIC)*
- aka *protected checksums*
- **Not a MAC:** a message digest: f(M) where f is a hash function.

Protocol: Digital Signatures

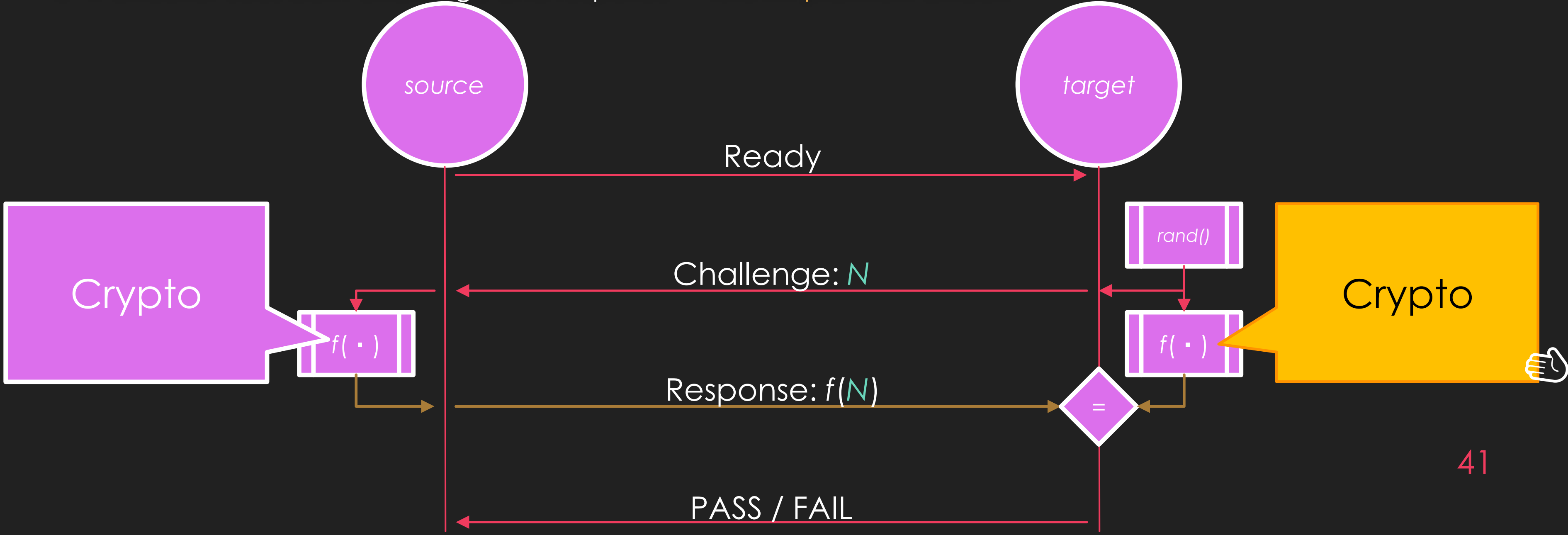
- Digital Signatures: using asymmetric crypto, for a message: create a value that can enable the message to be verified by any party with the public key but cannot be created by any party without the private key.
  - a signing party with a private key can create a signature
  - parties with the public key can verify that signature
- e.g. DSA, ECDSA. Let's consider a simple, older RSA signing:
  - Send message, M, and signature together



  - To verify: Decrypt $\{H(M)\}_k$ and assert it is equal to $H(M)$, where H is a cryptographic hash and k is the RSA private key
- In both MAC and Signatures, parties receiving messages that don't verify against the key (public in this case) shall discard messages
  - How the public keys are distributed and how messages are discarded is additional protocol details (for the next layer of the protocol specification)
  - e.g. what if they sent: $K\,|\,M\,|\,\{H(M)\}_k$ where K is the public key?

Protocol: Challenge-Response (C-R)

- Source wants to be authenticated by the target
- Source receives a nonce as challenge
- Transforms it and replies as response
- An ideal C-R would make it impractical for an attacker to guess the secret by observing traffic of multiple C-R exchanges.
  - If attacker sees both challenge and response ➞ *known plaintext attack*



Protocols
Section Summary

- **Protocols** – the rules that govern the communications between parties
- **Digital Signatures** – can be created by parties with the private key but verified by anyone with the public key (built from asymmetric crypto)
- **Message Authentication Codes** (MAC) – can be created and verified by any party with the key (can be built from symmetric crypto)

- **Nonce** "number used once" – can be random or a counter …
- **Simple Authentication** – source send its ID and an encrypted ID+nonce pair to a target for verification
- **Challenge Response** – target sends nonce to source; source replies with some proof that it has an ID known to the target
  - e.g. nonce encrypted with key known to source
  - e.g. nonce transformed with parameters known to source

Attacks on Protocols

Attacks on Protocols

- *Generally*: try to break the assumptions of the protocol
- This actually generalizes to “How to attack any specification”:
  - Anywhere the specification says SHALL/SHOULD – see what happens when it DON’T…

Attacks on Simple Authentication

- Simple Authentication assumes nonce N hasn’t been seen before
- If the nonce is random:
  - Does it actually check? ➞ Send again (Replay Attack)
  - How many nonces does it store? ➞ Send +1 (Valet Attack)

- If the nonce is a counter:
  - How does it resynchronize? ➞ Try sending counter guesses (Bad counter resync attack)

- Simple Authentication assumes that the key KT is associated with the ID T and
  - Are there other T that could associate with KT? ➞ Try sending to other target (Key collision attack)

Attacks on MAC

- For digests
  - Recall: these aren't actually MACs – but they get used that way occasionally
  - Recall: you will know the input, i.e. you will have at least one digest+message pair
  - You need to identify digest algorithm – length usually gives it away; also see tools like `cothan/hashdetector`
  - You may need to identify the salt also – `hashcat` can do this

- For HMAC- MD5, SHA1, …:
  - `hashcat` can crack the key or salt given a hmac+message pair

- Software exploitation, '*confused deputy*'
  - Software exploitation could enable control of what messages are sent by a piece of SW designed to send mac+message pairs.
  - Yields a successful forgery attack unless other software-integrity measures are taken.

Attack on Digital Signatures

- Recall the RSA Signature example: Send message, M, and signature together

$$M \mid \{H(M)\}_k$$

- Agreeing on the K public key for the k private key is a critical part.

  - What if the protocol includes the public key K?

$$K \mid M \mid \{H(M)\}_k$$

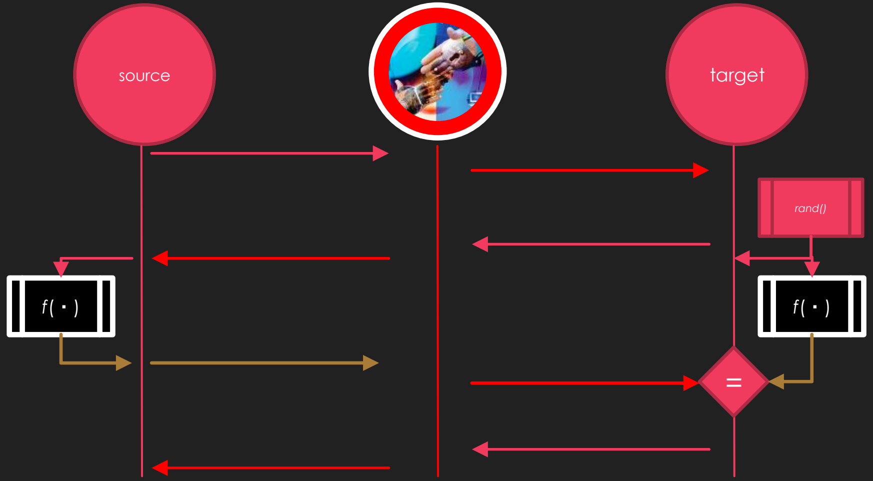
    - Then an attack is to use your own private/public key pair a/A and send:

$$A \mid M \mid \{H(M)\}_a$$

- Watch out for this broken protocol (sending the pubkey). It happens sometimes…
- More generally: try to find ways to substitute the expected public key K for your key, A
  - Stored in flash somewhere?

Attack on Challenge-Response: Middleperson Attack (in General)

- Interposing an actor in-between the source and target
  - aka MiTM
- Enables tampering with the contents, ordering, timing etc.
- Good concept for attacks on specific Challenge-Response protocols
- Definitely applicable in TLS/SSL attacks when you *can* interpose
- Can even be effectively achieved without physical interposition if messages can be selectively denied (e.g. CANT or CANHack attacks)



Attacks on Protocols
Section Summary

- Attacks on *protocols* are more fruitful than attacks on building blocks

- Simple Authentication Attacks
  - **Key Collisions** – e.g. 16bit serial number used as input to key
  - **Key Extraction and Extension** – e.g. Keeloq
  - **Replay Attack** – capture one or more, replay selectively
  - **Valet Attack** – capture a large set during temporary but extended possession
  - **Bad Counter Resynchronization** – depends on resync behavior of protocol
- MAC
  - Digests (broken), Hash breaking HMACs, shared-key reuse for MACs
- Digital Signature Attacks
  - Public key substitution
- Challenge-Response Attacks
  - Middleperson Attack
  - (and more coming up in later section)

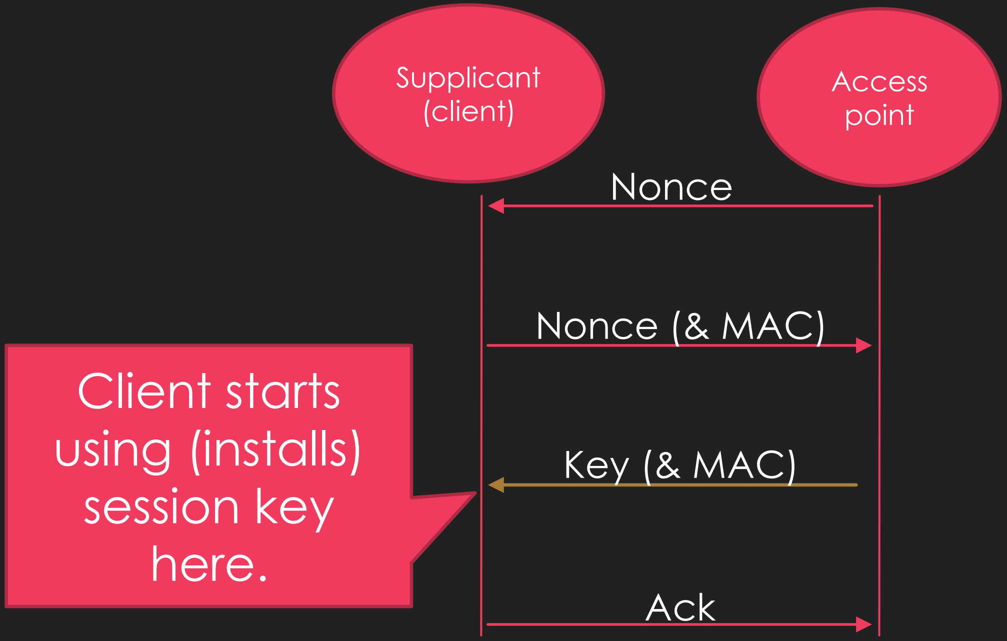
Protocol: WPA2

WPA2

- **Wi-Fi Protected Access 2**
- Wi-Fi confidentiality measure
- Supersedes WEP (which was a very broken protocol)
- WPA2-Personal (-PSK)
  - uses a pre-shared key.
  - Each client (supplicant in WPA-speak) gets its own session key
  - Setup of the key is visible at different levels.
- WPA2-Enterprise
  - Enables authentication of the Access-point
  - All communication with the Access-point is done with individualized keys

- Let’s discuss WPA2-Personal

WPA2 Handshake



4-way handshake

- A nonce
- Then another nonce with MAC
- Then a global key with MAC
- Then an ACK

Grossly over-simplified

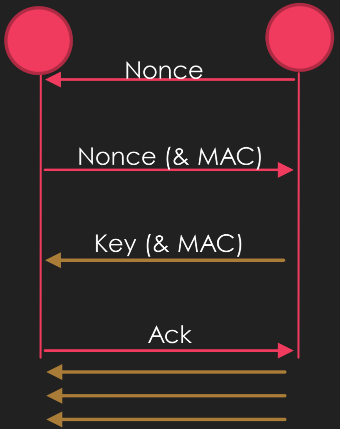
Attacks on WPA2

There is a MAC, implemented as a HMAC which is sent by supplicants and derived from the pre-shared key

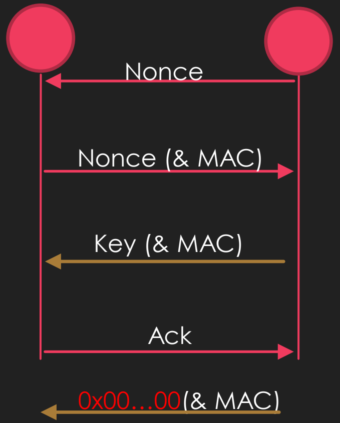
- Hash attacks to reverse this
- There are advantages to having observed multiple nonce & MAC -- so the attack starts with causing the target to deauthorize from the Wi-Fi (repeatedly)
- `hashcat` can do the cracking, but not the de-auth
- `airocrack-ng` can do both

Attacks on WPA2 (cont'd)

- There is a key reuse vulnerability in some client software, dubbed KRACK
  - When the key is 'installed', the client resets its communication counters
  - By replaying message 3 in the handshake, counters can be reset repeatedly – *key reuse attack*



- Some systems were even vulnerable to installing a null-key by sending a tampered 3rd message
- Fun-fact: WPA2 had been formally-proven secure.
  - The spec of the formal proof did not include "keys must be 'installed' once and only once"



https://www.krackattacks.com/

Hands-On: 1 Minute Challenge

Capture as many users of the Cybertruck Wi-Fi as you can in 1 minute.

I'm kidding – please don't attack the Wi-Fi. I'm using it.

- KRACK is unnecessary – your systems all know the WPA2 password already (it is a pre-shared key)
- How this *would* work :
  - 'de-auth' other clients so you could witness their handshake with the Access Point.
  - At which point you would have their session key and could decrypt all their traffic.

Protocol: WPA2
Section Summary

- WPA2 Passwords can be cracked, indirectly, via the hashes exposed in the handshake
  - The process is accelerated by capturing multiple 4-way handshakes, so the attack usually also includes a flood of de-authenticating the clients
- WPA2 keys can be reinstalled (KRACK)
  - Re-installing a key resets counters – this gives a key reuse attack
- Sometimes WPA2 keys can be nulled (KRACK)
  - Then follow up with known-key attack (v. simple in this case)

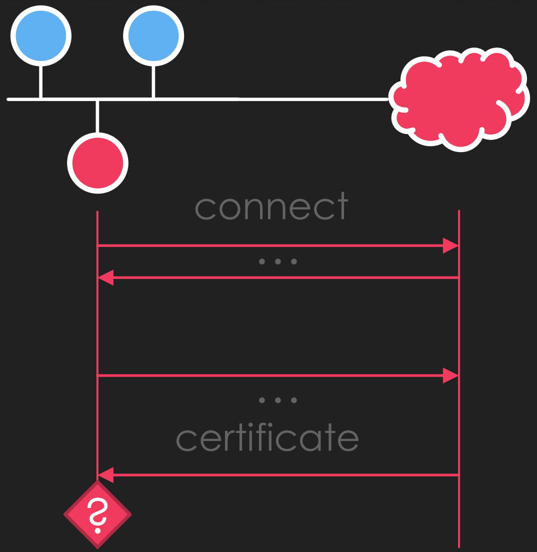
- These attacks on Wi-Fi require clients are connected

Protocol: TLS / SSL

Protocol: TLS / SSL

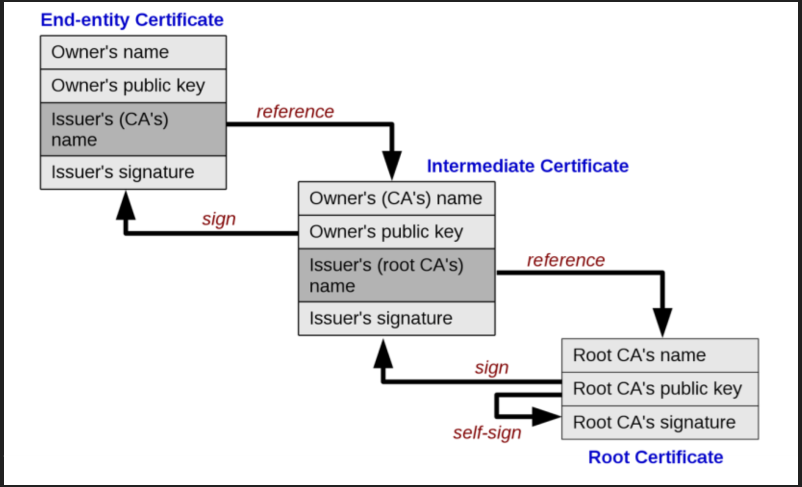
- Transport Layer Security (TLS). Was SSL, now that name is deprecated
- Used in HTTPS – but can be found without HTTP

- Provides both confidentiality and authentication of endpoints
  - typically client authenticates server
  - Sometimes server also authenticates client -- we're not going cover this



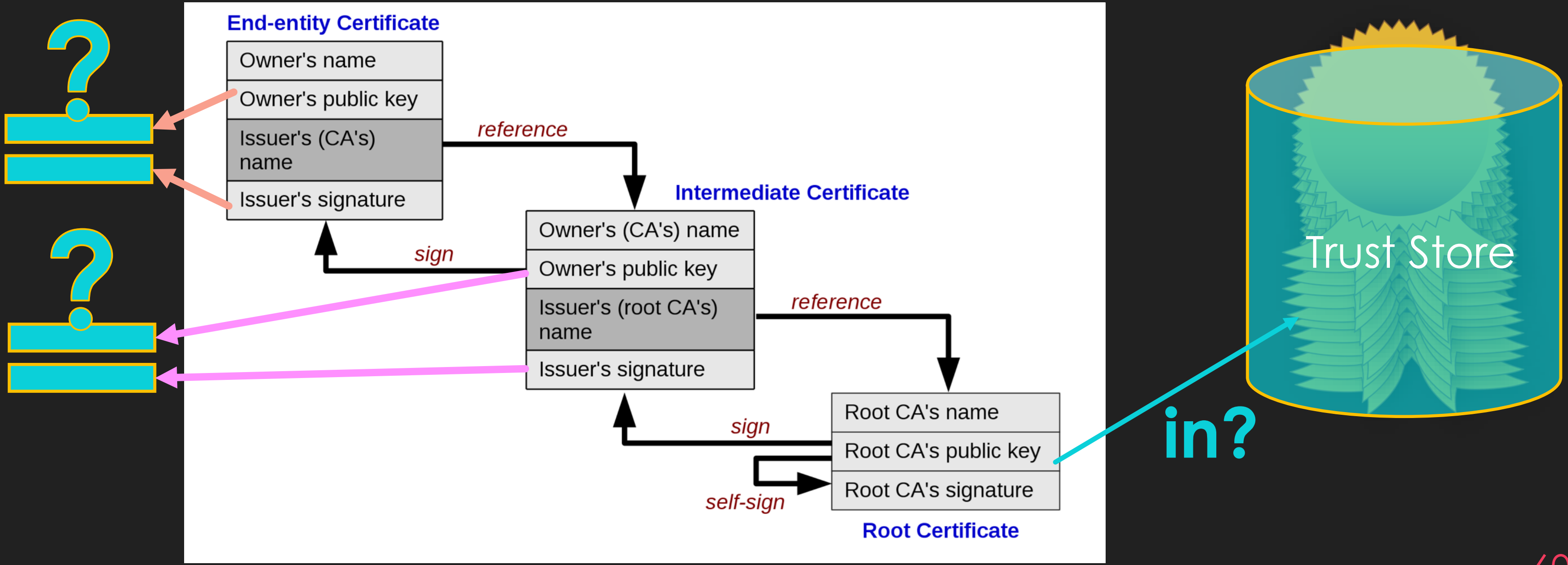
Certificates?

- Chains of Digital Signatures (asymmetric crypto)
- Recall: only the owner of the private part of a public key-pair can:
  - decrypt traffic encrypted to the public key
  - create a signature verifiable by anyone with the public key



By Yanpas - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=46369922

How Clients Are Supposed to Authenticate Servers



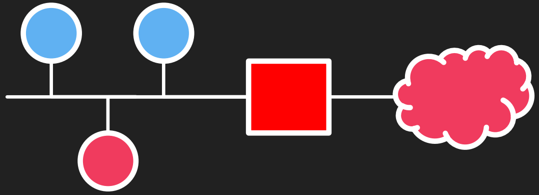
By Yanpas - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=46369922

Client Implementations of Server Authentication

"Type"	Trust
Type 1	Trust anything (no SSL/TLS)
Type 2	Trust any valid certificate
Type 3	Trust any root-CA in OS Trust Store
Type 4	Trust only (pin) the pub key of certificate
Type 5	Trust only (pin) the pub key of cert. signer
Type 6 0xc0de	Pinning and Integrity Verification

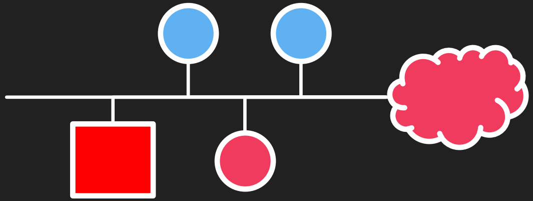
NB: The proxies will work out-of-the-box on Type 1 and Type 2

Middleperson (aka MiTM) Attacks



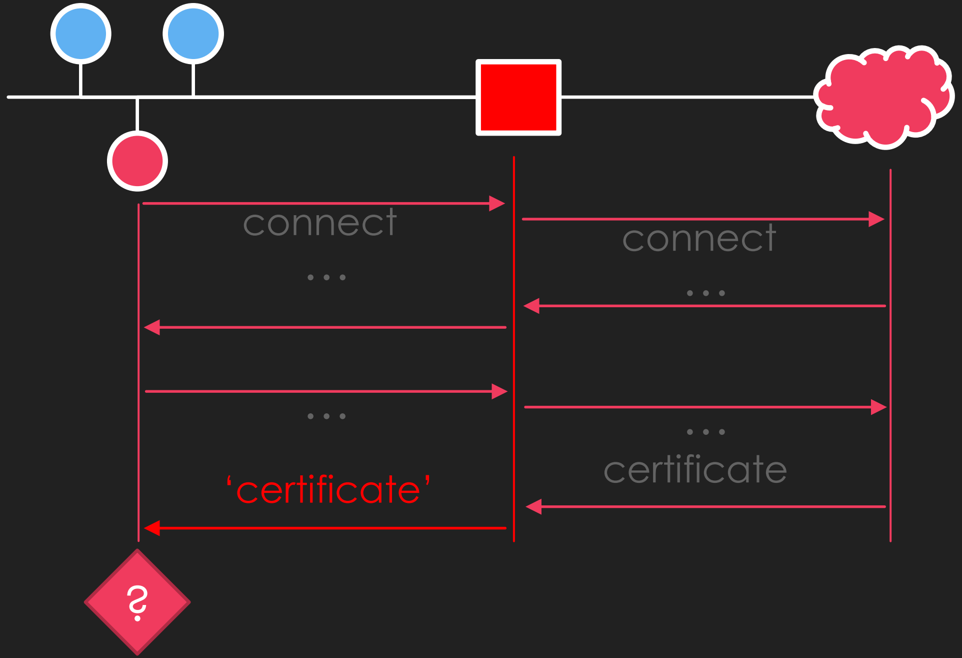
- HTTP Proxies: `mitmproxy`, Burp, ZAP, martian
- Non-HTTP: `MiTMF`, ettercap, bettercap, SSLSplit

- Some require that you setup the proxy as a gateway -- some can work as a sibling (leveraging ARP poisoning)



Certificate Substitution Attacks (on Type 2)

- Proxy creates two TLS connections
  - Upstream, client connection to server – normal, valid, nothing to see here
  - Downstream, served to client – supplies some other certificate
- Type 2 client sees 'a cert' and is happy



Trust Store Attacks (on Type 3)

- Can you add a root certificate authority to the trust store?
  - If you have UI access to an Android device the answer is probably yes

- Can you use a compromised root certificate that is already in the trust store?
  - There have been several compromised root certificates over the years (Komodo, Symantec)
  - If the devices is old enough, the compromised root certificate might be in its trust store
  - Forge a server certificate signed with the secret from the compromise root; install that in the proxy (e.g. `mitmproxy`, Burp, etc.)
    - Getting the compromised secret is… the tricky part

Types 4-5 Attacks

- Recall: types 4-5 use certificate pining – they will only accept a connection from a server with a particular expected public key
  - If a different public key is supplied they abort connections
- Software Exploitation is the only remote attack
- If you have superuser privileges on the systems executing the type 4-5 app then there are simple ways to replace the expected pub key or bypass the abort connection response:
  - Patch the pubkey from the software
  - Runtime hooking: e.g. **Universal Android SSL Pinning Bypass with Frida** https://codeshare.frida.re/@pcipolloni/universal-android-ssl-pinning-bypass-with-frida/

Types 6 Attacks

- The runtime integrity checks will prevent most patches, hooks and exploits.

Other Attacks (on all types)

- SWEET32 – monitor long-lived Triple-DES and recover cookies
- DROWN – break confidentiality of some TLS (downgrade)
- Logjam – break confidentiality and integrity of some TLS (downgrade)
- POODLE – break confidentiality and integrity of some TLS (downgrade)

- Not very practical – only PoCs available : `poodle-PoC` , `Tim---/drown` , `drownAttackDemo`

- There are even passive differential cryptanalysis attacks – working only at large-scale and long time periods
  - *Recover a RSA private key from a TLS Session with Perfect Forward Secrecy – Marco Ortisi*

- Other ‘other attacks’ (not confidentiality or integrity compromising):
  - Heartbleed – exploit memory leak in some OpenSSL versions to view 64K of server memory (in theory could yield a server secret)

Protocol: TLS / SSL
Section Summary

- TLS (SSL is deprecated) sets up a channel with confidentiality and authentication
  - Confidentiality is established with key-exchange
  - Authentication is established with certificate chain verification – the chain ultimately ending in an authority in a trust store of the endpoint
- TLS/SSL middleperson attacks require a network interposition and include:
  - Abuse of endpoints not checking certificate chains
  - Abuse of trust-stores – adding new authorities into them, or convincing users to do it
  - (rare) crypto breaks to obtain session or master keys
  - (less rare) forced downgrade to TLS/SSL version with publicly broken crypto
- Other TLS/SSL Attacks (some are aforementioned rare crypto breaks):
  - SWEET32, DROWN, logjam, POODLE, Heartbleed
- Tools:
  - `mitmproxy`, Burp, ZAP, `MITMf`
  - `poodle-PoC` , `Tim---/drown` , `drownAttackDemo`

Protocol: UDS Seed-Key Exchange

UDS

- Unified Diagnostic Services – ISO 14229 ; on CAN: ISO 15765
- Used for nearly ALL vehicle Diagnostic Protocols
- ~~You will learn *a lot* about it in other sessions today and tomorrow~~

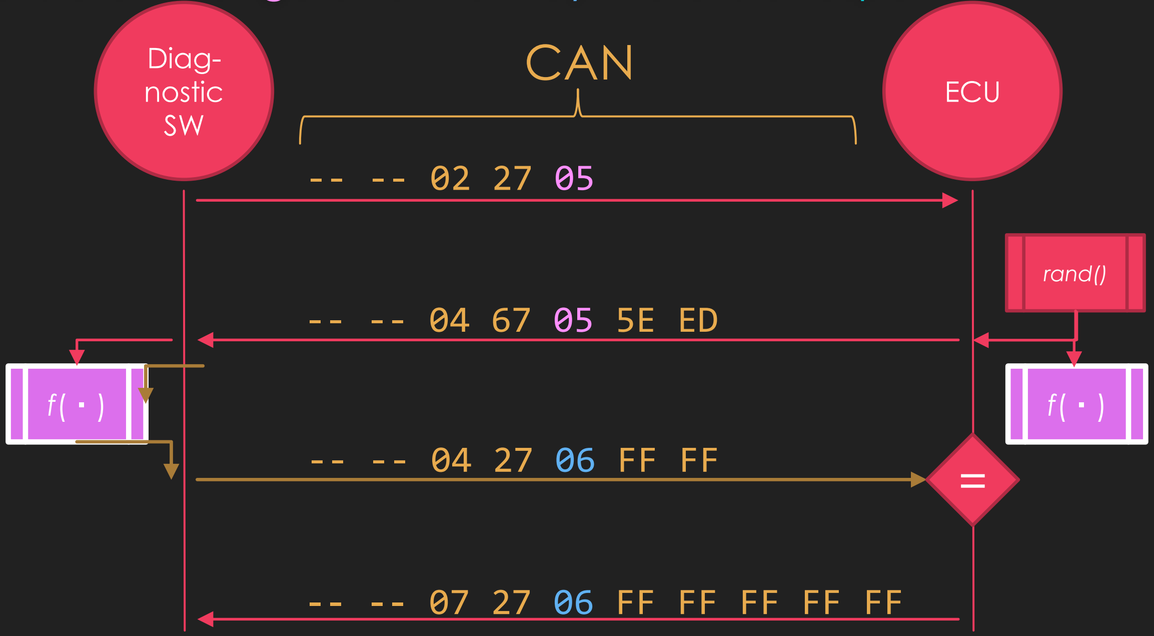
- There are actions in UDS that are protected. To execute the action requires authorization: e.g.
  - Read memory
  - Reflash ECUs
  - Perform potentially dangerous maintenance operations
  - ➢ aka ‘the fun stuff’

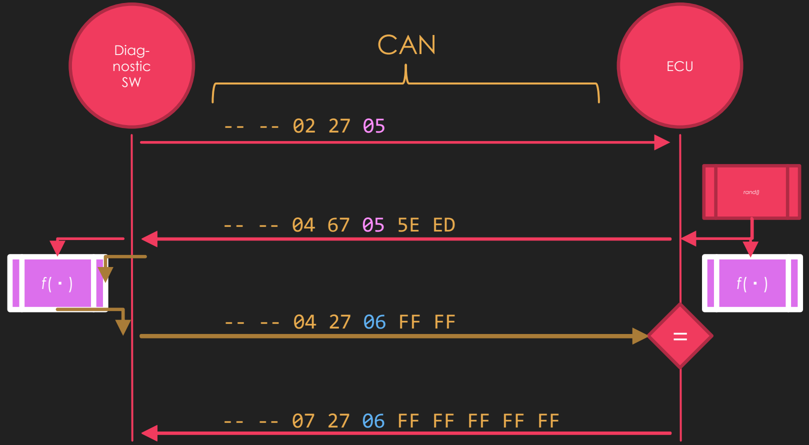
UDS Authorization

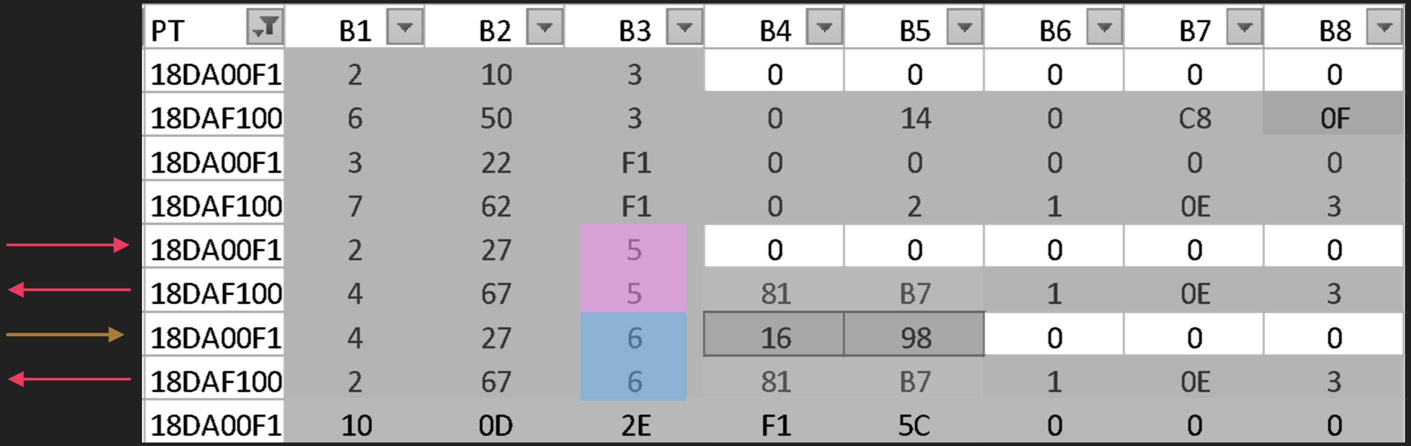
- Sometimes UDS is helpful; it will tell you that you need to authorize
  - Negative Response Code : SecurityAccessDenied
  - ~~You'll learn about these~~
- To authorize; unlock the current session with SecurityAccess Seed-Key Exchange
  - 'Session holder' (server) emits a '*seed*'; 'session user' (client) returns a '*key*'
  - Service 0x27 (replies on 0x67)
  - Subfunction 0x05 for requestSeed / 0x06 for sendKey
  - You'll know more about these soon

Seed-Key Exchange

- Seed-key exchange is a Challenge-Response Protocol
- Only 16-bit space; so it might not fit our ideal characteristics of resisting known plaintext forgery attacks
- The 'seed' here is a challenge and the 'key' here is a response







PT	B1	B2	B3	B4	B5	B6	B7	B8
18DA00F1	2	10	3	0	0	0	0	0
18DAF100	6	50	3	0	14	0	C8	0F
18DA00F1	3	22	F1	0	0	0	0	0
18DAF100	7	62	F1	0	2	1	0E	3
18DA00F1	2	27	5	0	0	0	0	0
18DAF100	4	67	5	81	B7	1	0E	3
18DA00F1	4	27	6	16	98	0	0	0
18DAF100	2	67	6	81	B7	1	0E	3
18DA00F1	10	0D	2E	F1	5C	0	0	0

Daily J., COMVEC15, *A Digital Forensics Perspective …*

NB: J1939 IDs 0x18DA00F1 and 0x18DAF100 are used for UDS over J1939

5 Minute Hands-On: Derive the Seed-Key Routines

1	2	3
18DAF100#0467055b31	18DAF100#0467050100	18DAF100#0467052c31
18DA00F1#0427065c31	18DA00F1#0427063435	18DA00F1#0427060005
18DAF100#0467053632	18DAF100#0467050100	18DAF100#0467053132
18DA00F1#0427063732	18DA00F1#0427063435	18DA00F1#0427061d06
18DAF100#0467052c31	18DAF100#0467050100	18DAF100#0467053732
18DA00F1#0427062d31	18DA00F1#0427063435	18DA00F1#0427061b06
18DAF100#0467053839	18DAF100#0467050100	18DAF100#0467053137
18DA00F1#0427063939	18DA00F1#0427063435	18DA00F1#0427061d03

‘Crypto’

Protocol: Seed-Key Exchange
Section Summary (see UNABRIDGED for missing STUFF)

- J1939 IDs `0x18DA00F1` and `0x18DAF100` are used for UDS over J1939
- SecurityAccess service is `0x27` / sub requestSeed: `0x05` sendKey: `0x06`

- If you have **diagnostic software**:
  - Reverse the key algorithm & parameters from PC software
  - Black-box / Lift the key algorithm & parameters
- If you have **ECU firmware**:
  - Reverse the key algorithm & parameters from firmware image (NB: you might have the wrong direction of algorithm)
- If you have **some captures** of successful SecurityAccess:
  - Solve for unknowns in a known formula from related ECUs
  - Retry seeds until a match occurs with one in the captures
- If you have **only the ECU**:
  - Brute-force (can you control the seed?)
  - Get some captures (e.g. service center) – see above
  - Glitch past the check – be amazing

Closing

Summary

- ’Modern’ crypto is about numbers / Classic ‘crypto’ is about alphabets
- ’Crypto is hard’ → means correct crypto is hard to break, if you have only the capture of communications

- Crypto building blocks don’t get broken very often (given only the capture of comms)
- Crypto *protocols* get broken
- Crypto gets broken via side-channels
- Crypto gets broken by compromise of execution environment

- You can middleperson-attack TLS/SSL
- You can lift/reverse/solve/brute-force Seed-Key Exchange

Resources for Continued Learning

- *Cryptopals* (CTF), T. Ptacek et. al.
- *Let's Play with Crypto* (Pres.), Ange Albertini
- Any and all SO answers by Thomas Pornin
- *Security Engineering* (Book), Ross Anderson
- *PotatoSec Crypto Puzzle Challenges*
- POC||GTFO (Journal), mirror