AP/ITEC 2210 3.0 A: System Administration Fall 2023

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Date/Time: Wednesday, 19:00-22:00
Location: Zoom / ACE 003
Office hours: Via Mattermost any time

Class 7 - Encryption, Security

- Final exam:
  - Date - location TBD
  - In person
  - Open book
  - Cumulative

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- Backups review:
  - The importance of offsite backups:

https://www.reuters.com/article/us-france-ovh-fire/fire-breaks-out-in-ovh-building-in-strasbourg-france-idUSKBN2B20NU

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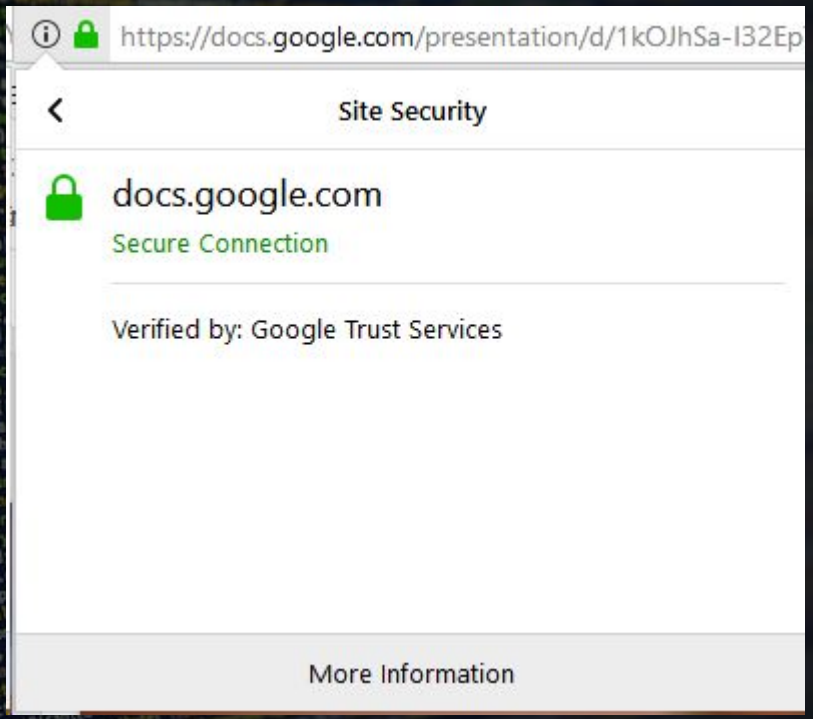

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- First some notes:
  - I *will* be oversimplifying or eliding details of some algorithms or maths in this Class - good crypto is hard!
  - However, as an SA the principles are important, regardless of implementation details, and I'm confident explaining those, so here goes!
  - The nature of cryptography (and security) is it has to be nearly perfect, or it will eventually fail to a smarter or better financed adversary

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- Cryptography principle 0
  - **Never design your own cryptography system**
  - You will get it wrong, someone will find a weakness
  - Idea is affectionately called **Schneier's Law**
  - An example analogy:
    - If you wouldn't design and strap yourself to your own rocket, you probably shouldn't design your own cryptosystem

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- Cryptography resources
  - Menezes, A. J., C., V. O., & Vanstone, S. A. (2001). *Handbook of applied cryptography*. Boca Raton: CRC Press.
    - Available free: **https://cacr.uwaterloo.ca/hac/**
  - **https://crypto.stackexchange.com** - It is the best kind of pedantry The links to primary and secondary sources are especially helpful
  - **NIST Federal Information Processing Standards (FIPS)**
  - **Wiki.openssl.org**
  - To prove crypto is 'fun' see **Schneier Facts**

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- Cryptography resources
  - Full course in breaking crypto systems (in order to learn about them in a practical way) here: https://cryptopals.com/

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- **Cryptographic attacks**
  - I'm not going to cover them since there are so many, but here are some side-channel (non-cryptographic) attacks that can be more effective than finding mathematical weaknesses in a crypto system
    - Black-bag cryptanalysis - physical theft
    - Man-in-the-middle attack - eavesdropping
    - Power analysis - what it says, crazy cool
    - Replay attack - replay encrypted data, e.g. WEP, WPA Handshake
    - Rubber-hose cryptanalysis - physical or psychological torture
    - Timing analysis - using CPU timings to glean information

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- **Cryptography basics**
  - Alice, Bob, Eve are the main actors who we'll encounter
  - Typical scenario is Alice and Bob want to communicate privately, and Eve wants to know what they're saying
  - **Plaintext** (message) is what they're communicating
  - **Ciphertext** is the encrypted version of the message

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- **Cryptography basics**
  - **Key** is the secret that is mixed with plaintext in an encryption algorithm to produce a ciphertext
  - **Keyspace** is the size of all possible key values, e.g. $2^{\wedge 2048}$
  - **Key schedule** is an algorithm that expands a key from say, 128 bits to thousands of bits for later use in an encryption operation
  - **Block cipher** algorithms operate on chunks of data at a time
  - **Stream cipher** algorithms operate on bits of data at a time

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What does encryption Look like?

From HAC ch1 p.13

E - encryption function
D - decryption function
m - message
c - ciphertext

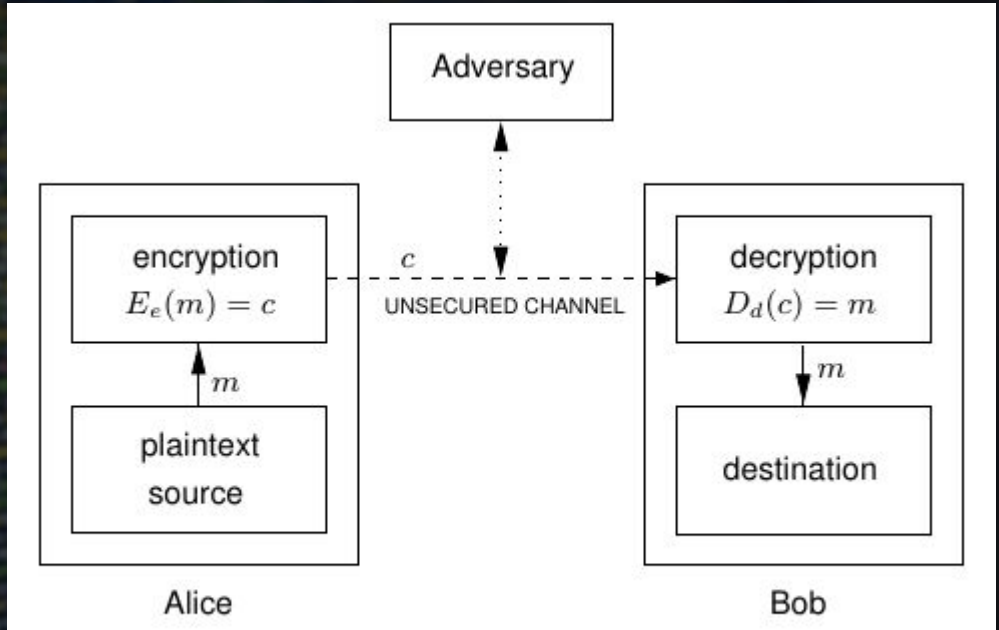

Figure 1.6: *Schematic of a two-party communication using encryption.*

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- Cryptographic **operations**:
  - **Substitution:** A=C, B=D, C=E, D=F - Caesar cipher
  - **Transposition:** plaintext is reordered
  - Bitwise operation: bits are **XOR'ed**
  - **Round**: composition of operation(s) on a plaintext

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- Cryptographic **operations** (from HAC, ch1, p.20):
  - **Substitution** in a round adds **confusion** to a ciphertext
    - Idea is to make the relationship between encryption key and ciphertext appear complex
  - **Transposition** adds **diffusion** to a ciphertext
    - Idea is to rearrange and spread out non-uniform bits in a message to statistical patterns, common letter combinations

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- Cryptography basics
  - XOR:
    - 1 XOR 1 = 0
    - 1 XOR 0 = 1
    - 0 XOR 1 = 1
    - 0 XOR 0 = 0
  - Tie in to last week's RAID5/6 Class and how XOR & parity works: https://igoro.com/archive/how-raid-6-dual-parity-calculation-works

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- Cryptographic **Hash functions**
- Map an **input** of any arbitrary length binary string to a fixed length unique binary string (**hash**) that represents the input
- Take the string `itec2210.ca` and run it through a hashing algorithm (use a terminal on your VM):
  - echo 'itec2210.ca' |md5
    b44f302d2e8f77c54455ce7b7b6f08ba
  - python -c 'print("A"*100)' |md5
    0d6aa8e34b2af058d6e4a27d7ff511dd

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- Cryptographic **Hash functions**
- python -c 'print("A"*100)' |md5
  0d6aa8e34b2af058d6e4a27d7ff511dd
- No matter how long the input, output is always 128 bits
- Likewise with SHA1/2/3, e.g:
- python -c 'print("A"*100)' | shasum -a 256
  f76262cff1f14a9eb92d57ac0de2b8dc431f3c0fe3e88f9394140f68024066b7 -

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- Cryptographic **Hash functions**
- Now repeat the same input to the algorithm:
- python -c 'print("A"*100)' | shasum -a 256
  f76262cff1f14a9eb92d57ac0de2b8dc431f3c0fe3e88f9394140f68024066b7 -
- python -c 'print("A"*100)' | shasum -a 256
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- Cryptographic **Hash functions**
- Notice how the output never changes?
- The same input will always produce the same set of output bits
- Enables checking things like:
  - File contents are unmodified
  - Encrypted data is intact
  - Email message signatures
  - Password entries in databases
  - TLS browser encryption

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- Cryptographic **Hash functions**
- Map an **input** of any arbitrary length binary string to a fixed length unique binary string (**hash**) that represents the input
- It should be difficult to find two separate inputs that map to the same hash output (a **collision**) (SHA-1 bruteforce odds being $2^{\wedge 80}$, or $1.2x10^{\wedge 24}$)
- 1,200,000,000,000,000,000,000,000
- Moreover, given a hash, it should be infeasible to work backwards and find an input: algorithm is not reversible
- But wait:

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- Cryptographic **Hash functions**
- Common hashing functions you'll encounter:
  - MD5 - **BROKEN**
  - SHA-1 - **BROKEN**
  - **SHA-2** - current standard but getting weaker against attacks
  - **SHA-3** - recently released (as of 2015), variable length digests
  - **Bcrypt** - can be made to run arbitrarily slow to prevent bruteforce
  - Hash functions have lifetimes of decades at best
  - As computer power grows, speed of finding collisions does too

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- Cryptographic **Hash functions**
- Used extensively to create digital signatures, like SSL/TLS certificates, document signatures, email encryption
- Also used to ensure data integrity, like file transfers over untrusted networks, e.g. Debian, Ubuntu, RedHat, Fedora, software repositories
  - http://centos.mirror.iweb.ca/7/extras/x86_64/repodata/repomd.xml.asc
  - http://centos.mirror.iweb.ca/7/extras/x86_64/repodata/repomd.xml
- Note: signature is a hash of the data, which is then encrypted with the private key - later we'll see how the public key decrypts the signature

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- **Symmetric** and **Asymmetric** encryption

- **Symmetric** - both parties share a secret encryption key
  - Can be **block** or **stream** based
  - **AES** is the current generally accepted standard for symmetric (**block**) encryption
  - **AES** encryption algorithm uses 16 byte blocks
  - Example would be a passphrase on an encrypted disk volume

  - **RC4** is an example of a (broken) **stream** cipher
    - WEP encryption used RC4 in Initialization Vector (IV)
  - Many block ciphers can be used in stream mode

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- **Symmetric** and **Asymmetric** encryption
- **IV aside** - visit wikipedia article, it is very helpful
  - Initialization vector or starting value is used to ensure that repeated use of a key on duplicate plaintext results in different ciphertext
  - Usually IV is mixed with key in the algorithm's state machine as part of a key schedule or keystream
  - In most block cipher modes IV will be stored with a block of ciphertext

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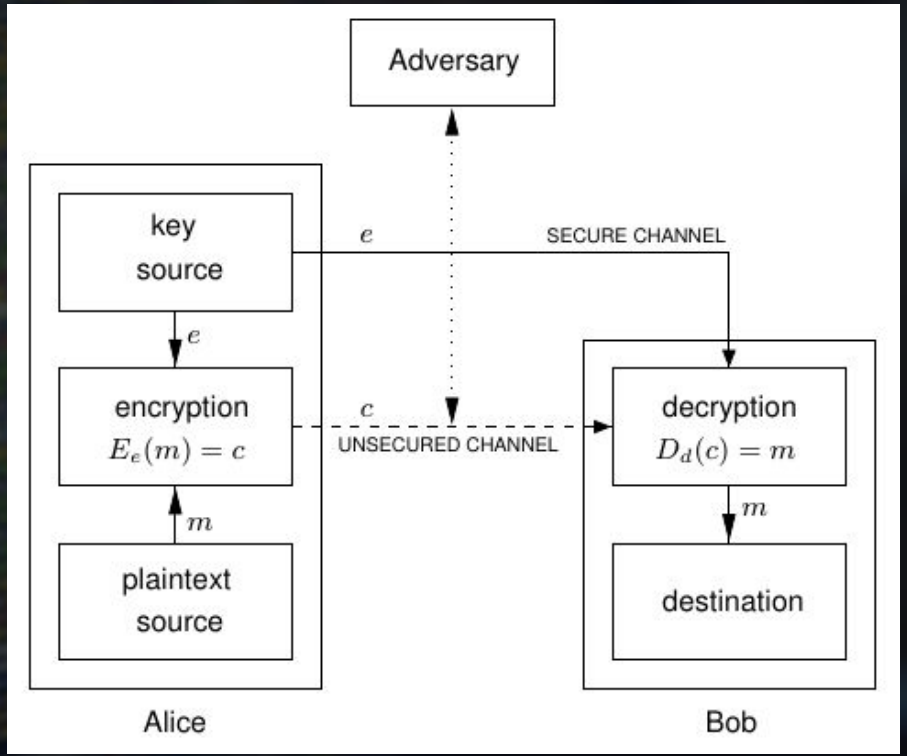
- **Symmetric** encryption
- HAC ch1 p.16



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- **Symmetric Encryption - AES**
- Designed by extensive consultation with cryptography community and standards bodies
- Intent was to replace DES (2^{56} bit key combinations, 7.2×10^{16})
- AES has:
  - **2^128** or 3.4×10^{38} possible keys (128-bit);
  - **2^192** or 6.2×10^{57} possible keys (192-bit); and
  - **2^256** or 1.1×10^{77} possible keys (256-bit)

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- **AES**
  - “Assuming that one could build a machine that could recover a DES key in a second (i.e., try 2^{55} keys per second)
  - then it would take that machine approximately 149 thousand-billion (149 trillion) years to crack a 128-bit AES key.
  - To put that into perspective, the universe is believed to be less than 20 billion years old” (Since AES was published, WMAP determined it is likely 13.77 ± 0.059 billion years)

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- **AES**
- So what does AES actually look like?
- https://formaestudio.com/rijndaelinspector/archivos/Rijndael_Animation_v4_eng-html5.html
- It is worth taking your time with it

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- **Symmetric** and **Asymmetric** encryption
- **Asymmetric (AKA Public Key)**
  - Designed around a pair of large prime numbers (**key pair**) and some modular arithmetic, with one number being private, and the other public
  - The public key is used to encrypt a value, which only the private key can decrypt
  - Example would be **RSA** algorithm, used for **PGP/GPG**
  - Think of it like a locked mailbox where anyone can put a letter in, but can't take a letter out without the key

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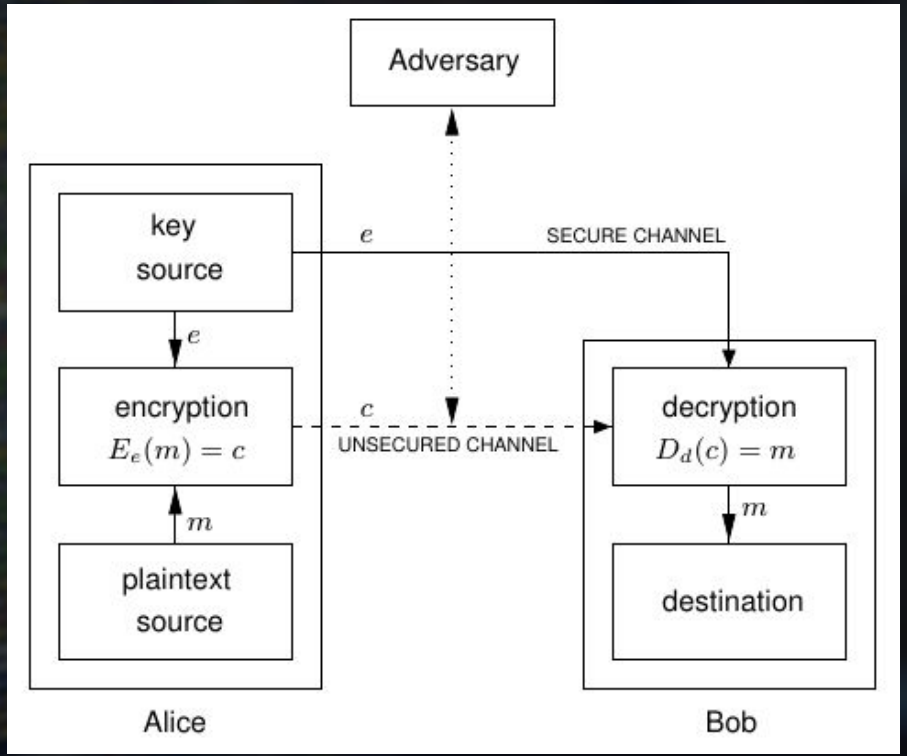
- **Recall symmetric** encryption
- HAC ch1 p.16



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- **This is asymmetric** encryption
- HAC ch1 p.28

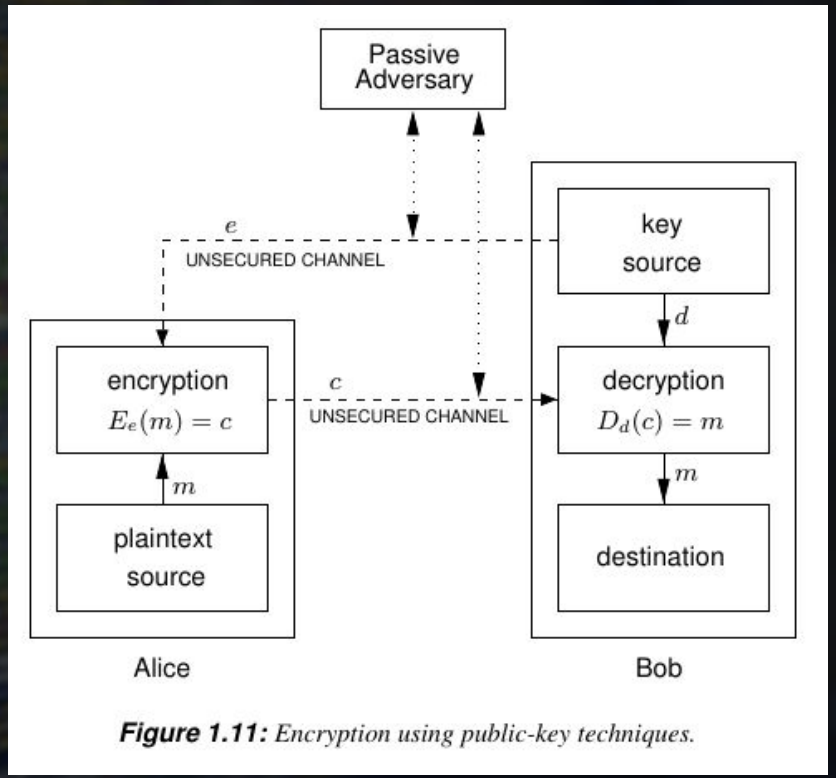

Figure 1.11: *Encryption using public-key techniques.*

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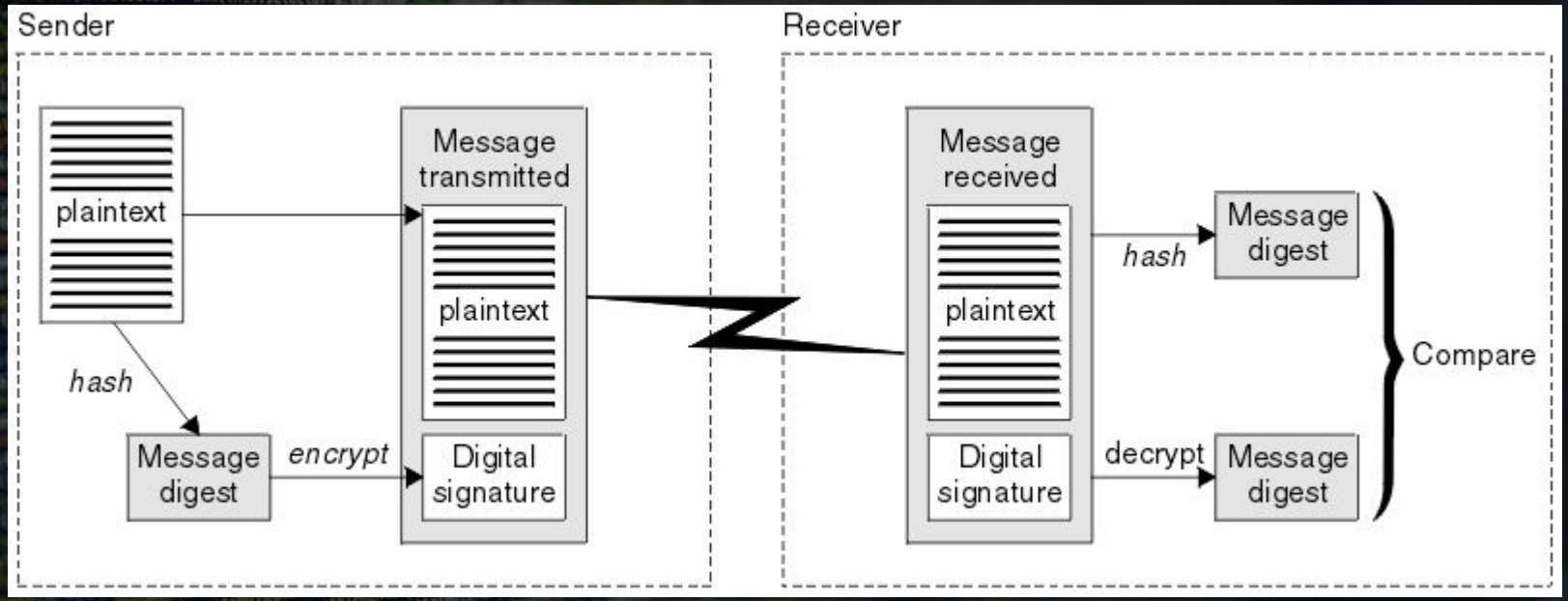
- Cryptographic hash used for digital signature



https://www.ibm.com/support/knowledgecenter/SSFKSJ_7.1.0/com.ibm.mq.doc/sy10520_.htm

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- **Asymmetric encryption**
  - Public key can encrypt a message that can only be decrypted with the private key
    - Used for secure communication
  - Private key can encrypt a message that can only be decrypted with the public key
    - Used for authentication and signatures
  - Bear with me here, the idea is to see that the following works
  - Recall modulus arithmetic: *10 mod 3 ≡ 1*

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- **Asymmetric RSA encryption** (from HAC ch8 p.286)
- Algorithm components are:
  - 1. Generate two large random (and distinct) primes p and q, each roughly the same size
  - 2. Compute $n = pq$ and $\varphi = (p - 1)(q - 1)$
  - 3. Select a random integer e, $1 < e < \varphi$, such that $gcd(e, \varphi) = 1$ (e is coprime with phi, that is, their only common divisor is 1)
  - 4. Use the extended Euclidean algorithm (Algorithm 2.107) to compute the unique integer d, $1 < d < \varphi$, such that $ed \equiv 1 \pmod{\varphi}$
  - Otherwise expressed as $ed / \varphi = 1$
  - 5. A's public key is (n, e); A's private key is d

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- **Asymmetric RSA encryption** (from HAC ch8 p.286)
- Example:
  - https://simple.wikipedia.org/wiki/RSA_(algorithm)

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- **Asymmetric RSA encryption** (from HAC ch8)
- That *e* part
  - 3 is a good candidate because it makes small values for computation, but can lead to broken encryption if the same message is sent to multiple recipients
  - 65537 is a good value, because it is 0x10001 in hex, or 1000000000000001 in binary which makes for easy computation
  - Take a look at an OpenSSL generated RSA certificate, it is likely that it will use this value. Also ‘openssl genrsa -h’
  - Many RSA implementations choose e first, then check that phi is coprime with e

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- **Asymmetric RSA encryption**
- Alice and Bob can now communicate securely with each other by encrypting messages with the other person's public key
- They can also sign their own messages to prove to the other person that they were the original sender, and that the encrypted message was not tampered with in transit
- Eve can listen in all she likes, and if Bob and Alice chose some large primes, Eve probably won't decrypt any messages until after the heat death of the universe

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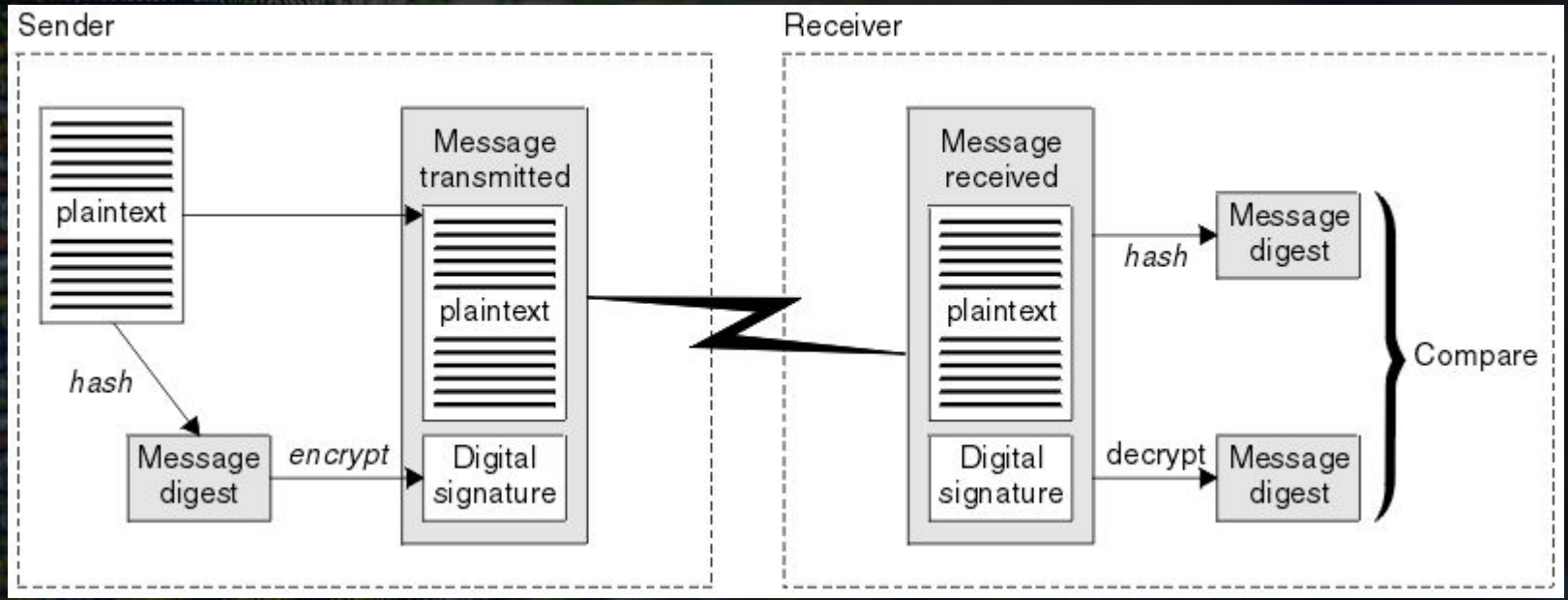
- Now, brief X.509/SSL/TLS certificate aside - remember this?



https://www.ibm.com/support/knowledgecenter/SSFKSJ_7.1.0/com.ibm.mq.doc/sy10520_.htm

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- Now, brief X.509/SSL/TLS certificate aside
- **RSA** is one possible algorithm in this signing and hashing scheme
- ‘Plaintext’ is set of fields, like domain name, location, expiry dates
- As well as *e* and *n* from the RSA keypair (public key)
- A 3rd party **Certificate Authority (CA)** digitally signs the certificate with their private key, essentially validating you are who you say you are in the certificate

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- Now, brief X.509/SSL/TLS certificate aside
- **/etc/ssl/certs** on your VM contains 3rd party CA (certificate authority) certs, tools like curl, apt rely on these for security
- Your browser and OS will also contain a vetted list of CA certificates
- You can validate a certificate that a CA has signed with their private RSA key based on the principle of reversing encryption using the public key
- Say, for example, a bank's TLS certificate, which itself has a public RSA key in it. Use the key to decrypt signatures, and encrypt messages

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- **Asymmetric encryption**
- Ok, back to Bob and Alice
- What if Alice and Bob have never met, but want to exchange messages using a shared secret key?

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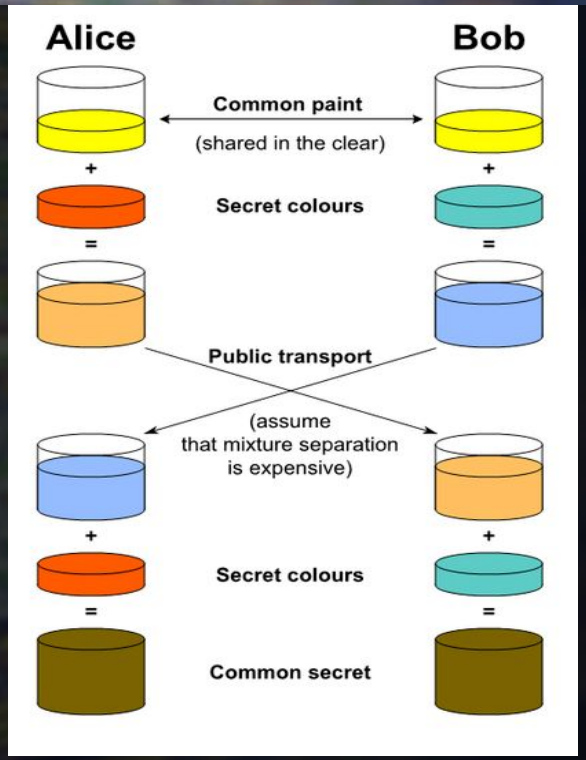
- Enter Diffie-Hellman algorithm



https://en.wikipedia.org/wiki/Diffie%E2%80%93Hellman_key_exchange

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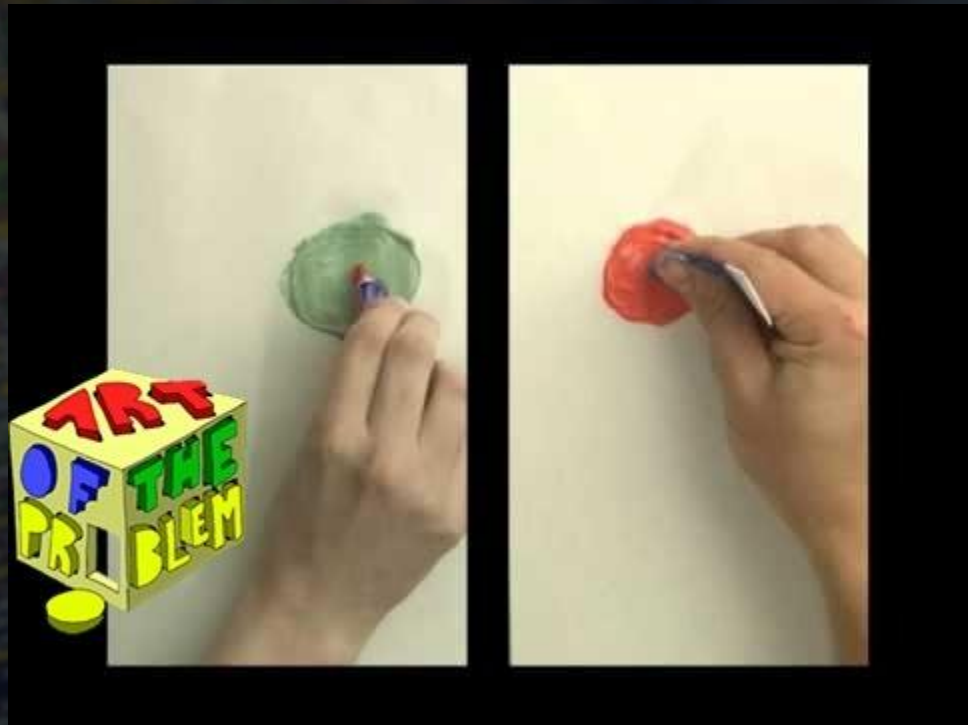
- Diffie-Hellman key exchange
- **Logjam vulnerability**
  - **See also cloudflare**



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- **Putting it all together**
- What if two parties who have never met would like to exchange secure messages? Say a credit card transaction online
- Recall our tools so far:
  - **Hash functions** - **SHA-1**, **SHA-2**, **SHA-3**, **MD5**
  - **Symmetric ciphers** - block and stream, **AES, ChaCha20**
  - **Asymmetric encryption**
    - **RSA** algorithm
    - **DH** algorithm
  - **X509/SSL/TLS certificates** containing **CA** signed public keys

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- TLS handshake

  “When a TLS client and server first start communicating, they agree on a protocol version, select cryptographic algorithms, optionally authenticate each other, and use public-key encryption techniques to generate shared secrets.”

- TLS parameters

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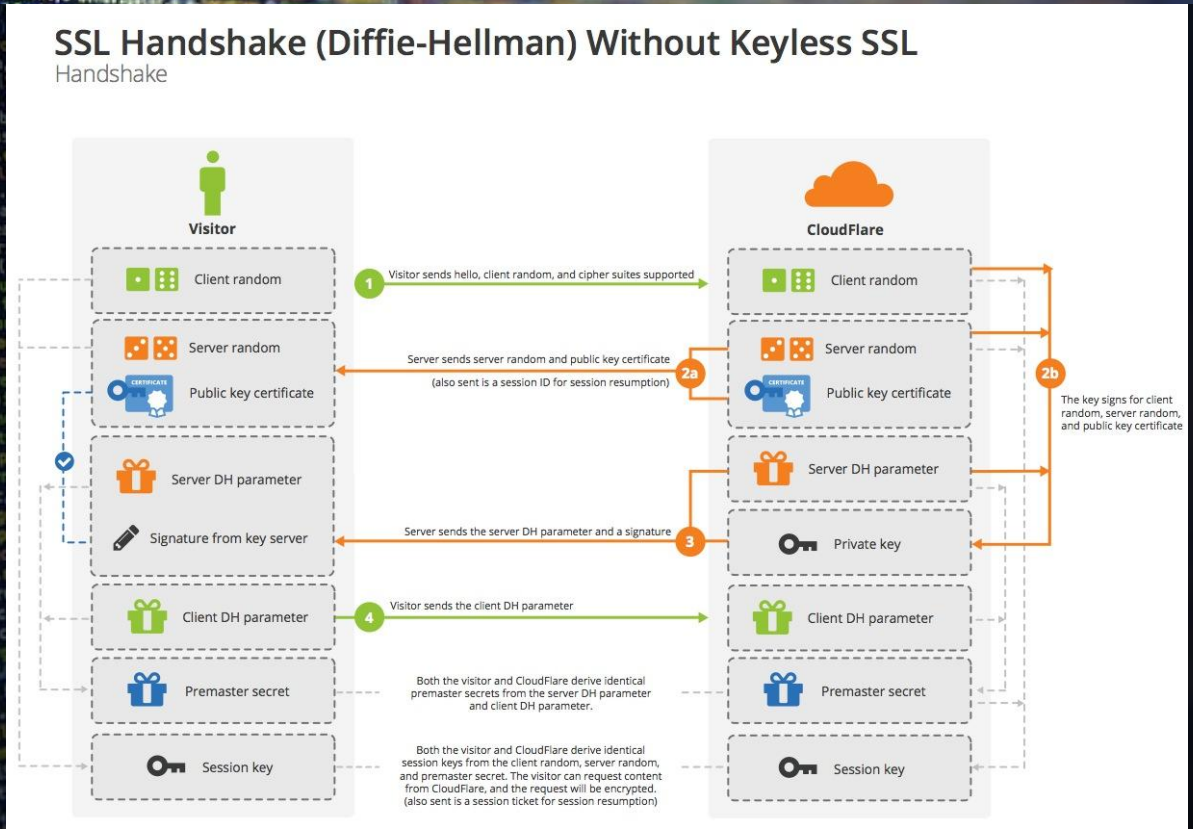

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- Best Explanation I’ve seen:
  - https://tls12.xargs.org/
- To be continued next week!