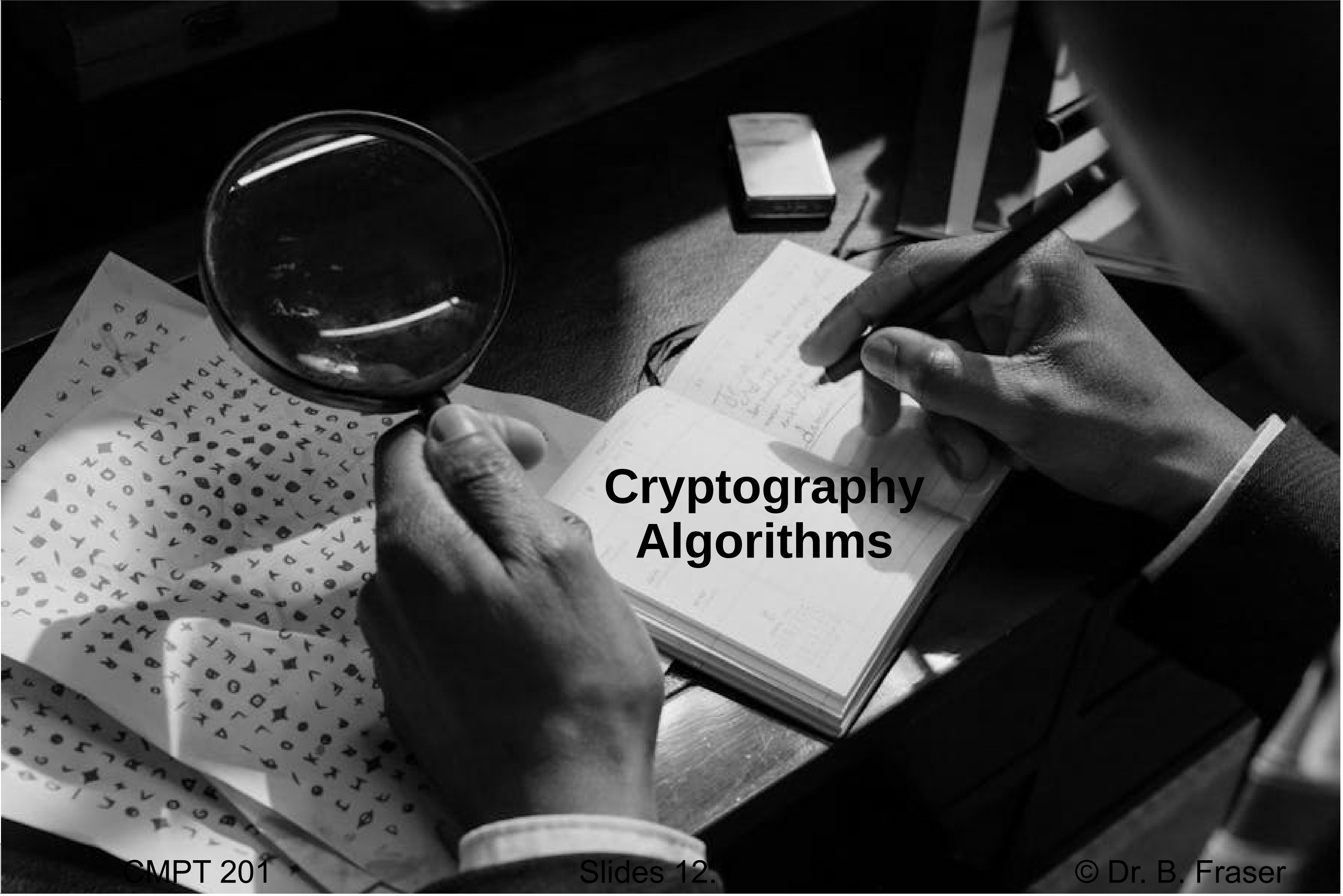


Cryptography Algorithms

Topics

- What is cryptography?
- What are the basics of cryptographic algorithms?
  - What are cryptographic hashes?
  - What is a secret key encryption?
  - What is public-key encryption?

Cryptography:
The absolute basics

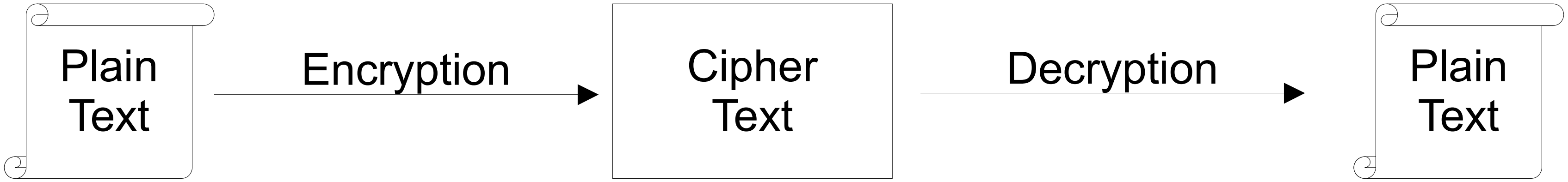
Context

- Cryptography
  - A very broad area.
  - We'll focus on how to *use* cryptography.
  - We just touch on the basics!

The CIA Model

- CIA model: the classic security model.
  - Confidentiality:
    ..
  - Integrity:
    ..
    and only by authorized parties.
  - Availability:
    ..
- Threat examples
  - Against confidentiality: classified information leak
  - Against integrity: fake images/videos
  - Against availability: Denial-of-Service (DoS) attacks

General Cryptography Process



- Cryptographers invented secret codes
  to hide messages from unauthorized observers.
- Challenges:
  - How can you hide a message from everyone but the intended recipient?
  - How can the recipient know the message is authentic?

ABCD: Traditional Cryptography

- Traditional Cryptography:
  - Secret codes, which are secret algorithms.
  - E.g., Caesar Cipher: ..

    For +1 ‘A’ becomes ‘B’.
- ABCD: Which of the following is the cipher text from using a 3-letter shift Caesar Cipher on the plain text “Hello world”?

```
a) EBIIL TLOIA
b) KHOOR ZRUOG
c) IFMMP XPSME
d) LOWOR LDHEL
```

- What is the problem with a secret algorithm?
  - When your algorithm (or code book) is compromised, ..

Modern Encryption

- Algorithms are Public
  - ..
  - May be symmetric (secret key) or asymmetric (public key).
- Why is this better?
  - If algorithm or code is secret,
    then if it falls into the wrong hands it means code is useless.
  - If only key is private,
    then if it falls into the wrong hands then
    ..

Crypto Algorithm Goals

- Choose an encryption algorithm such that:
  - Given a key, it should be

    ..
  - Without a key, it should be

    ..
- Strength of security often based on length of key:

  Longer key is more difficult to guess (by brute-force).

Window of Validity

- Window of Validity
  ..
  - Must only use algorithm that have not been compromised.
- Problem:
  Window of validity of your crypto function
  ..
  - Design systems so you can replace the crypto function easily.
- Example Windows of Validity
  - 1993: SHA-0 was published.
  - 1995: Possible weakness was found in the SHA-0 algorithm; replaced with SHA-1.
  - 2004: Published way to compromise SHA-0
  - 2017: Published way to compromise SHA-1
  - ????: Published way to compromise SHA-256?

Three Types

- Types of cryptography algorithms based on their keys:
  - Zero keys: ..
  - One key: ..
  - Two keys: ..

Cryptographic Hash Functions (Zero Keys)

Cryptographic Hash Functions

- Suppose we have a cryptographic hash function *h()*
  - It takes a message *m* of arbitrary length as input and ..
- Toy example:

  $\boldsymbol{h(m) = (m^2)\ \%\ 4321}$

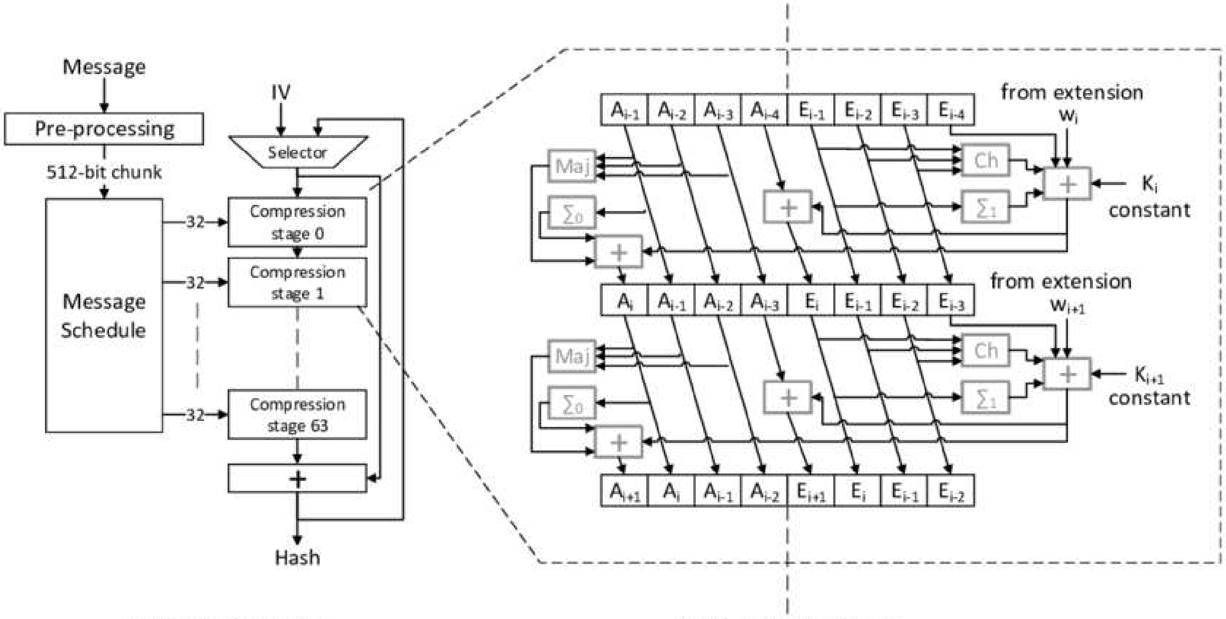
```
 m    m in hex              h(m)
AAAA (0x41414141) -->    2242
BBBB (0x42424242) -->     893
CCCC (0x43434343) -->    2558
DDDD (0x44444444) -->    2916
EEEE (0x45454545) -->    1967
FFFF (0x46464646) -->    4032
GGGG (0x47474747) -->     469
HHHH (0x48484848) -->    4241
IIII (0x49494949) -->    2385
JJJJ (0x4A4A4A4A) -->    3543
KKKK (0x4B4B4B4B) -->    3394
LLLL (0x4C4C4C4C) -->    1938
```

Hash Function Properties

- ..
  - It should be easy to compute *h(m)*
- ..
  - Given *h(x)*, it should be difficult to find *x*.
  - i.e., the reverse of *h()* should be difficult to compute.
- ..
  - Given x, it should be difficult to find *x'* where *h(x') == h(x)*
  - i.e., Given a value and a hash function, it should be difficult to find another value that produces the same hash.
- ..
  - It should be difficult to find
two messages *x* and *x'* where *h(x) == h(x')*
  - i.e., given a hash function, it should be difficult to find two values that produce the same hash.

Ideal Hash

- Ideally, we want all these properties
  for a strong cryptographic hash function.
  - However, not all hash functions provide all these properties.
- Example good crypto hash function: SHA-256.



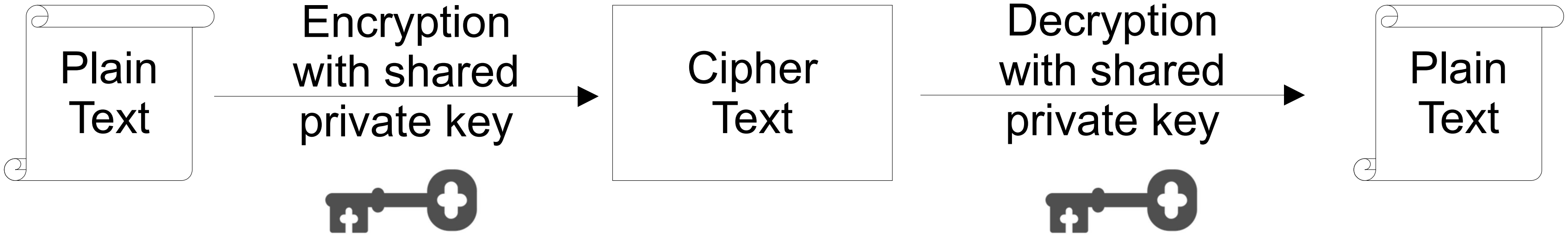
(a) SHA-256 Function

(b) Compression Stages

https://www.researchgate.net/figure/SHA-256-algorithm-block-diagram-a-SHA-256-execution-flow-including-the-preprocessing_fig3_371457507

Private Key Cryptography
or
Symetric Key Cryptography
(One key)

Private (Symmetric) Key Crypto



Plain Text

Encryption with shared private key

Cipher Text

Decryption with shared private key

Plain Text

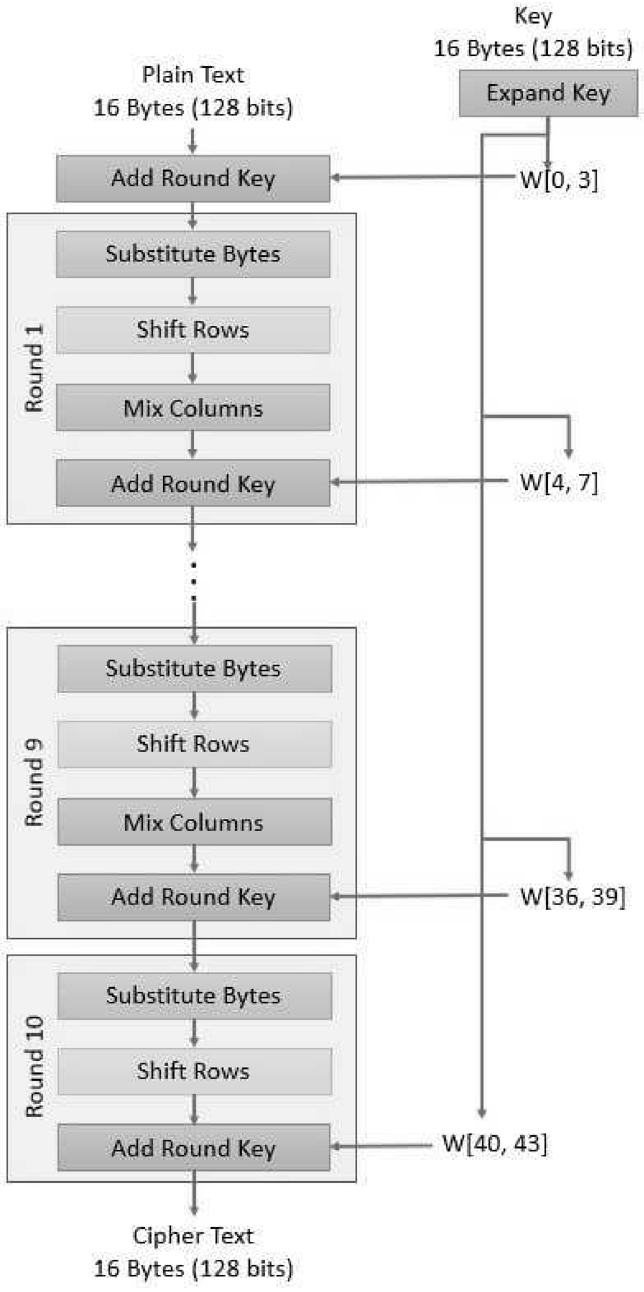
- One key:

  ..

  - ..
  - This was the only type of encryption prior to invention of public-key in 1970's.

Private Key Crypto: AES

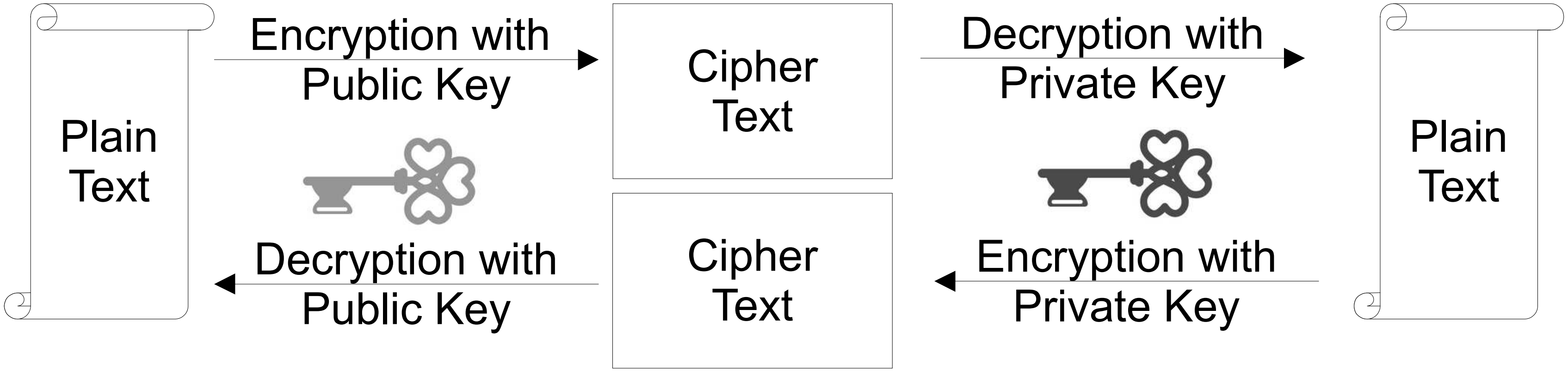
- AES is an example private key crypto algorithm
  - Need the same key to encrypt and decrypt.



https://binaryterms.com/advanced-encryption-standard-aes.html

Public Key Crypto
or
Asymmetric Crypto
(Two keys)

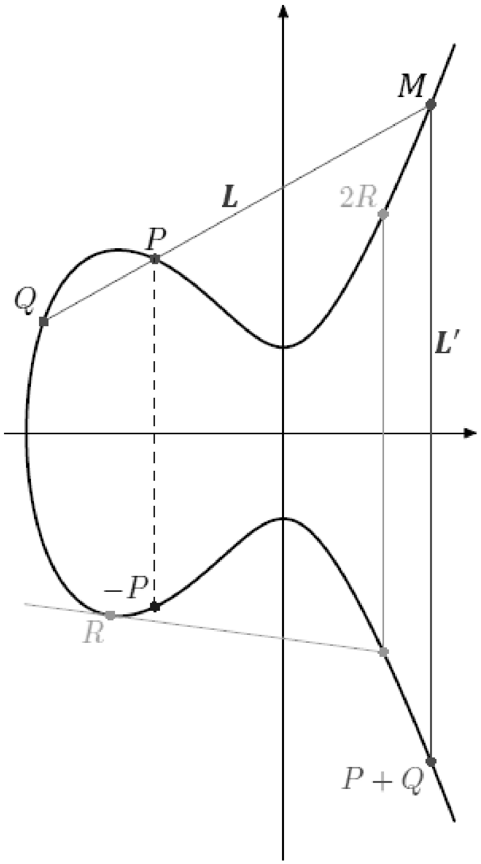
Public Key Crypto (Asymmetric)


Plain Text
Encryption with Public Key
Cipher Text
Decryption with Private Key
Plain Text
Decryption with Public Key
Cipher Text
Encryption with Private Key

- There are two keys:
  - Public key: can be known to anybody
    - Used to encrypt and verify signatures (more below).
  - Private key: ..
    - Used to decrypt and sign signatures (more below).
- Fundamental property of public key encryption:
  - ..

Generating Keys

- Generating keys:
  - The public and private keys are ..
- Example approaches to generating keys
  - Factoring very large prime numbers,
  - Solving "Twisted Edwards curves" (ed25519)



https://www.researchgate.net/figure/Elliptic-Curve-Addition_fig1_284494383

Keeping Secrets

- Example: Keeping Secrets
  - Alice wants to send a secret message to Bob
  - ..
  - Bob decrypts the cipher-text using his private key
- Analysis
  - Since only Bob knows Bob's private key,
only Bob can decrypt the cipher-text.
  - Hence Alice and Bob can securely share the message.

Verifying Sender

- Example: Verifying Sender
  - Bob wants Alice to know that he sent a messages and it has not been altered.
  - ..
  - Alice decrypts the cipher-text using Bob's public key.
- Analysis
  - Since only Bob knows Bob's private key,

    ..
  - Alice knows it was Bob who created the message.

Secret and Verified

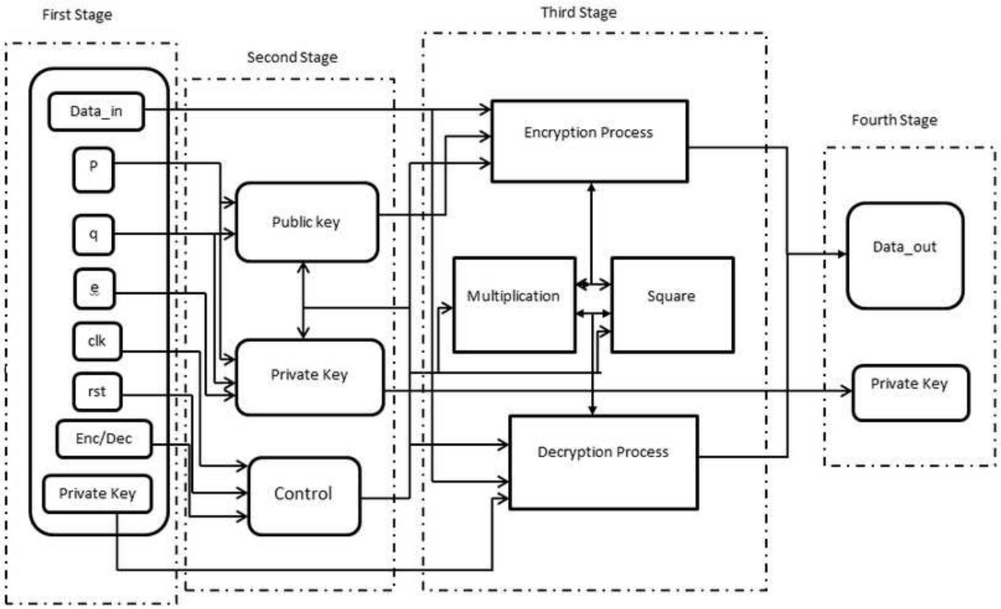
- Example: Secret and Verified

  Combine previous two examples.

  - Alice wants to send a verified, secret message.
  - ..
    - Anyone can decrypt it with her public key.
    - But only she can encypt with it; so we know she sent it!
  - ..
    - Only Bob can decrypt it with his private key.
- Analysis
  - Only Bob can decrypt the message (using his private key), and he'll know that only Alice can create it (using her private key).

Public Key

- Benefit:
  - This does not require having
    ..
  - Lots of other use cases beyond encryption / decryption
- Example algorithm: RSA.



https://www.researchgate.net/figure/RSA-Algorithm-Process_fig3_282249995

Summary

- Cryptography
  - From plain text, create cipher text that others cannot read or change.
- Types of algorithms
  - 0 Keys: Hash function
  - 1 Key: Symmetric encryption (private-key)
    - Both sides know the same secret key.
  - 2 Keys: Asymmetric encryption (public-key)
    - You share a public key with the world.
    - Anyone can encrypt messages for you using this key.
    - Only you can decrypt messages using your secret private key which matches the public key.