



Mag. iur. Dr. techn. Michael Sonntag

Introduction to Cryptography

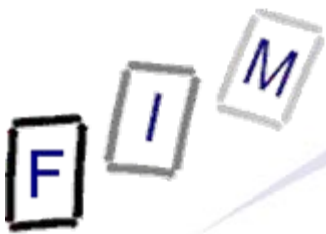
Security and Privacy
VSE Prag, 7 - 11.6.2010

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- General aspects
 - Why and where to use
- Technical aspects
 - Symmetric vs. asymmetric cryptography
 - Algorithms and their strength, required environment
- Encryption/signing: Diffie-Hellman, RSA, AES
- Hash algorithms: MD5, SHA-1, SHA-256
- Certificates
 - Content, PKI, revocation
- SSL/TLS
 - Modes, protocol
- VPNs: IPsec, PPTP, OpenVPN

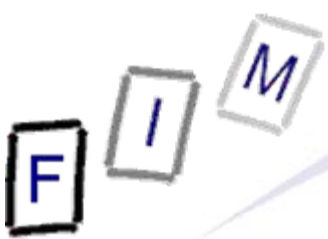


Why cryptography?

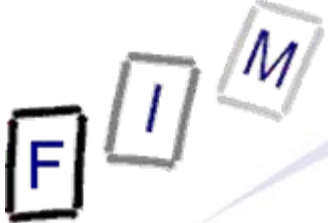
- Security is a very important aspect, especially if money (or equivalents) is contained in transactions
- Not everything information should be available to everyone
 - Note: Data is sent in the Internet over numerous "open systems", where anyone can listen it!

Security is needed!

- The technical aspect of security is cryptography
 - Encrypting data against disclosure and modifications
 - Signing data against modifications and repudiation
- Note: Cryptography **does not** solve **all** security problems!
 - Example: Communication analysis (who talks to whom when)
 - Other aspects of security are also needed
 - » E.g.: Do you know what your employees actually do with data?
 - Solutions: DRM, deactivation codes, anonymizers, ...

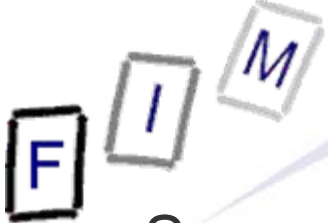


- Storing data in encrypted form
 - Even access will not lead to disclosure (Stolen Laptops!)
 - Example: File/file system encryption programs
- Transmitting data securely
 - Enc. transmission prevents eavesdropping and tampering
 - Example: TLS
- Identifying your partner
 - Preventing man-in-the-middle attacks
 - Example: TLS with uni-/bidirectional certificates
- Proof of identity
 - Avoiding impersonation
 - Example: GPG E-Mail signatures, digital signatures ("Bürgerkarte")



- Data is being
 - transmitted
 - stored
 - processed
- and exposed to the following attacks:
 - Inspection: without / with understanding
 - Modification: without / with understanding
 - Deletion: random / targeted
 - Addition: random / targeted
 - Replay: with / without knowledge of consequences

Those cases where the attacker can understand the data/consequences (here underlined), are more problematic!

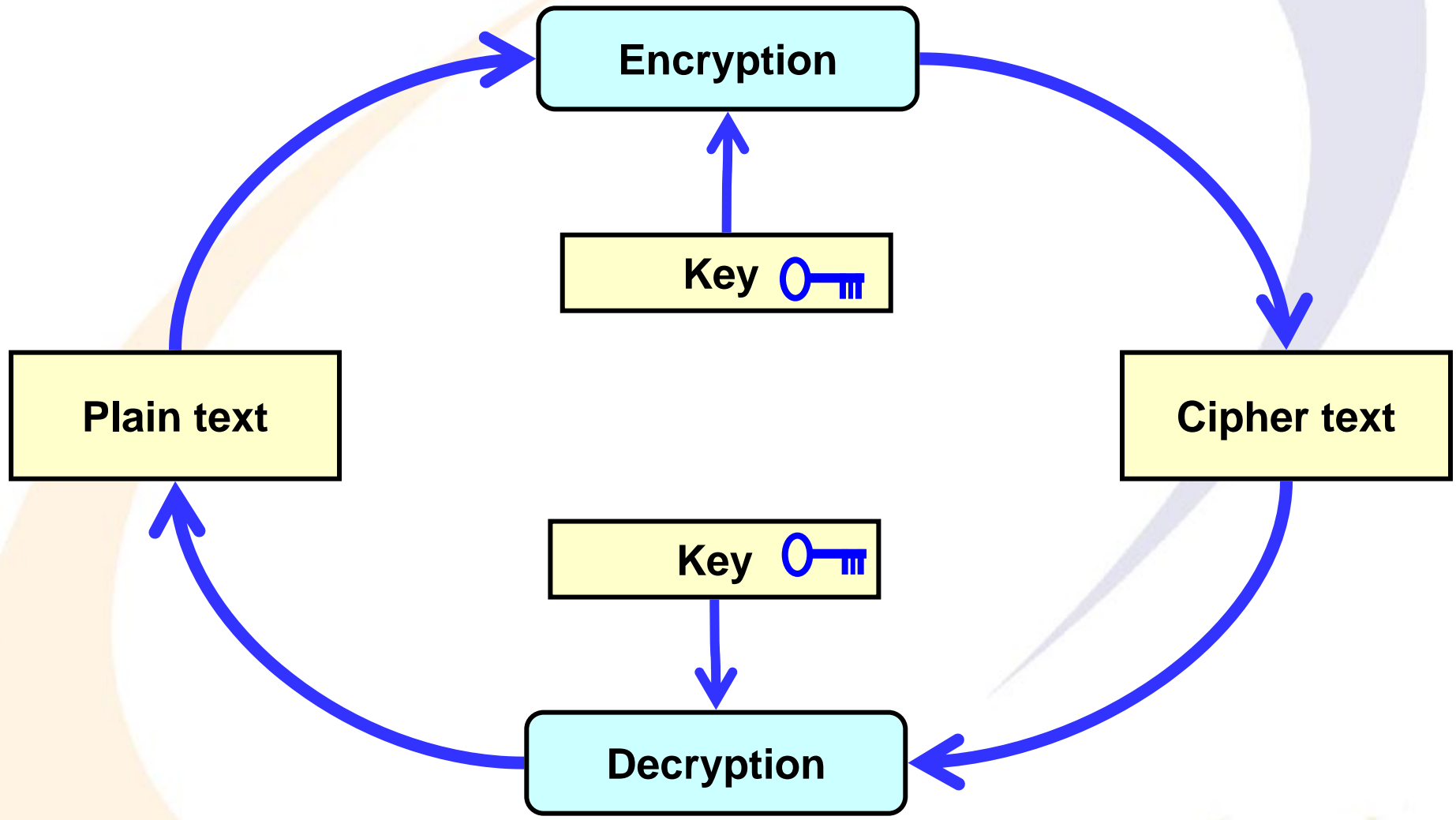


Software components

- Several different classes of algorithms required:
 - Hash functions: Handling the whole document takes too long
 - » Drawback: Content could be substituted (collisions)!
 - Encryption/Decryption: The same algorithm for symmetric, but different one for asymmetric encryption/signatures
 - » Encryption: Combining a document with a public key
 - » Signature: Combining a document with a private key
 - » Verification: Checking a document + signature with public key
 - Key agreement: Creating a shared secret
 - » Even if both parties do **not** have a shared secret to start with!
 - » Especially useful if the communication channel is insecure
 - Key generation: Creating secure keys
 - » Requires e.g. secure random generators
 - » From passwords: Creating keys suitable for algorithms
- For each class several/many algorithms exist
 - Some good, some bad (=broken, erroneous, ...)



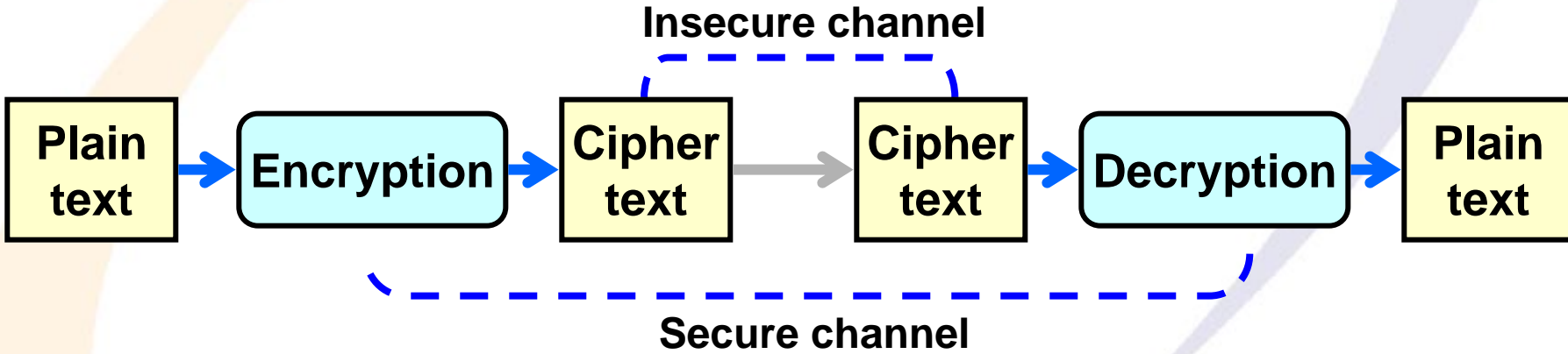
Basic functionality cryptography



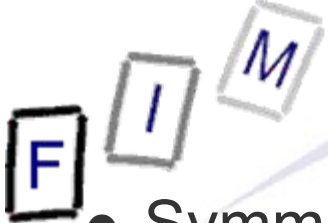


Common requirements

- Key comparatively very small
- Data to encrypt very large



Gutmann P.: „Network Security: Security Requirements“, University of Auckland,
<http://www.cs.auckland.ac.nz/~pgut001>

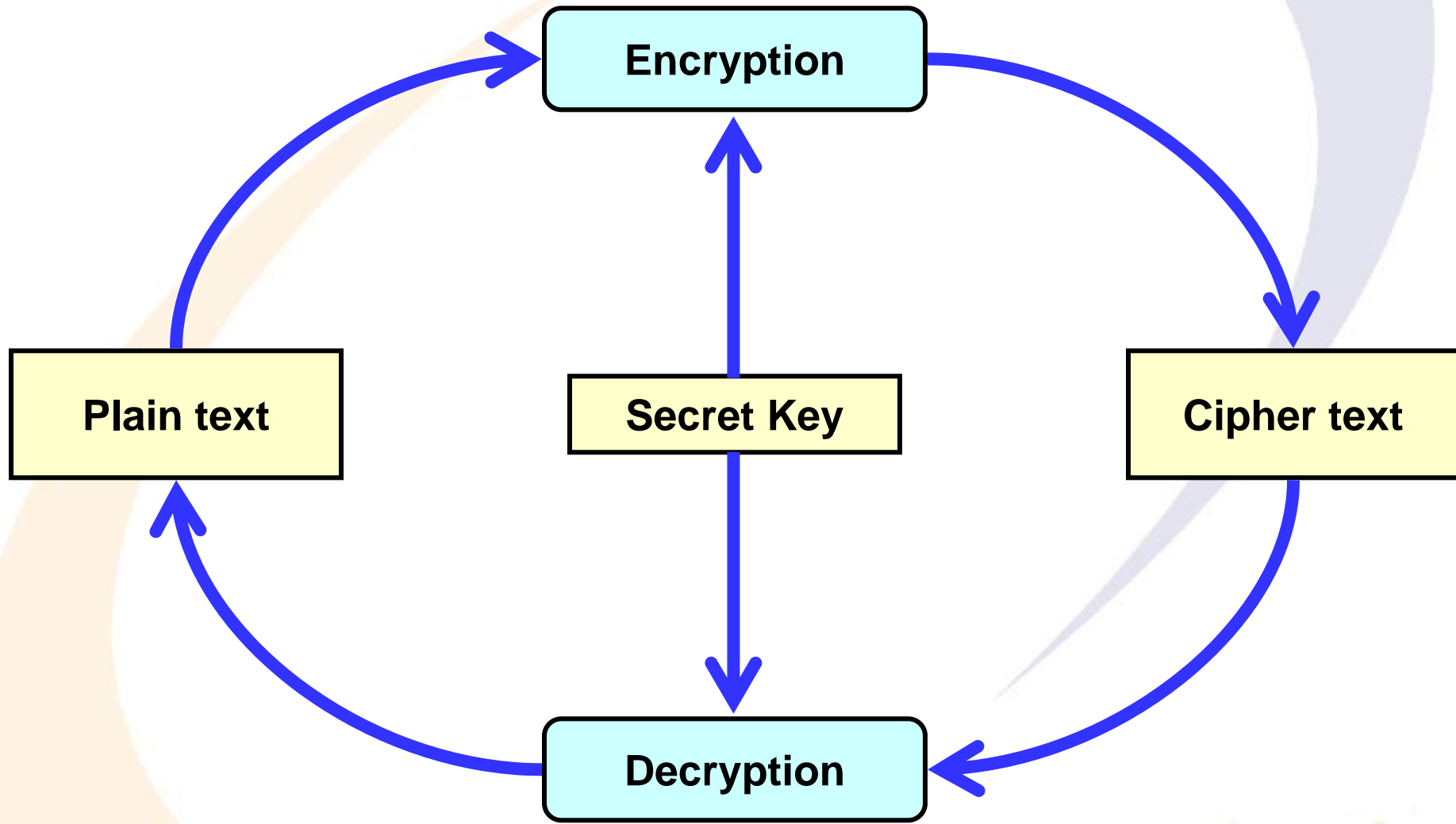


Symmetric vs. asymmetric cryptography

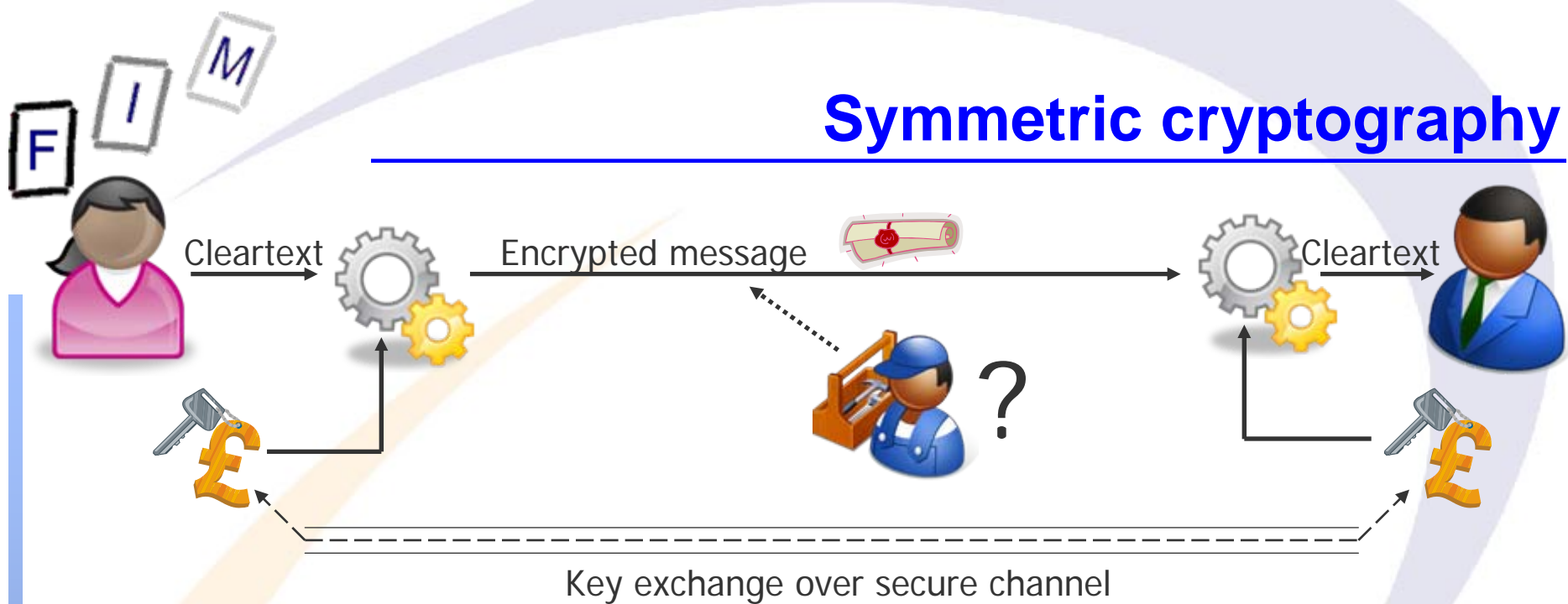
- Symmetric cryptography: Very old
 - Keys are short: ≥ 56 Bits (DES)
 - » Many algorithms known (many of them now insecure!)
 - Well suited to a large (homogenous) group of participants
 - » Everyone knows the same key and can en-/decrypt messages from all others
 - Key distribution: Problematic (Secure channel needed)
 - Computationally very fast (1/100 – 1/1000 of asymm.)
- Asymmetric cryptography: Very new (≈ 1970)
 - Keys are long: ≥ 512 Bits (RSA/DSA; Ell. curves ≥ 112)
 - » Few algorithms known (most of them very secure)
 - » Keys consist of two parts: One public, one private
 - Only suitable for a single person
 - » Encrypt TO this person or verify signatures FROM this person
 - Certification distribution: Problematic (common TTP needed)!
 - Computationally slow: Calculation difficult/time-consuming



Symmetric (secret key) encryption



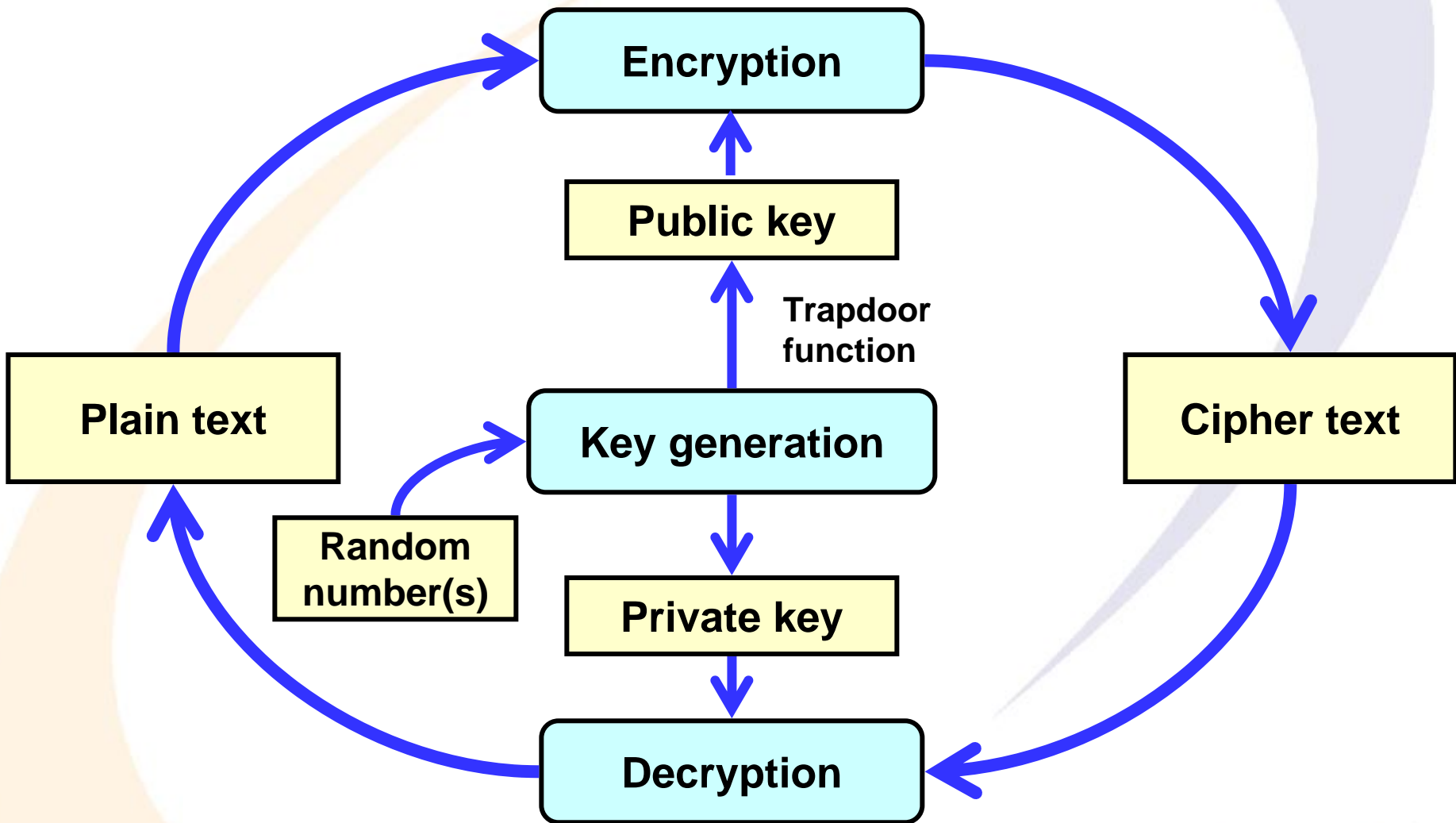
Symmetric cryptography



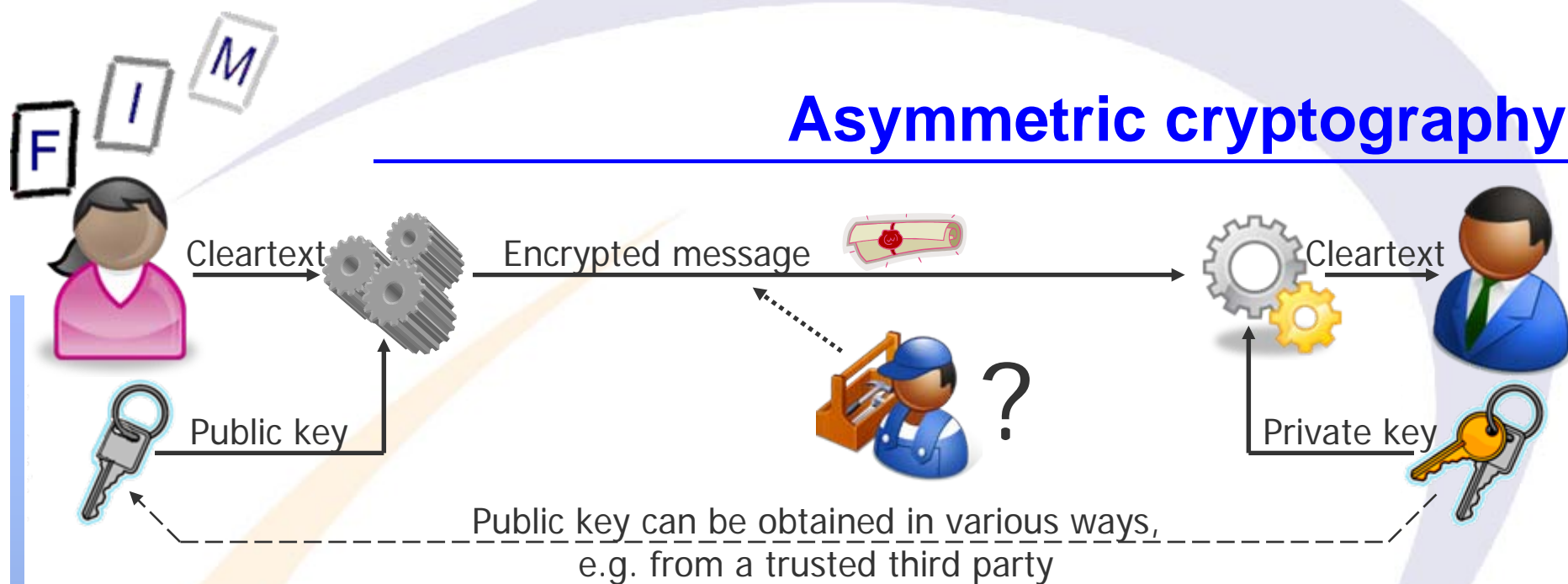
- The same key is used for encryption and decryption
 - The key must therefore remain absolutely secret!
 - So it must be transported to each other securely
 - » This is only possible through a different channel!
 - Keys must be changed regularly (much encrypted content renders breaking the encryption easier!)
- Also used for authentication (repudiation possible!)
 - "MAC" Message Authentication Code



Asymmetric (public key) encryption



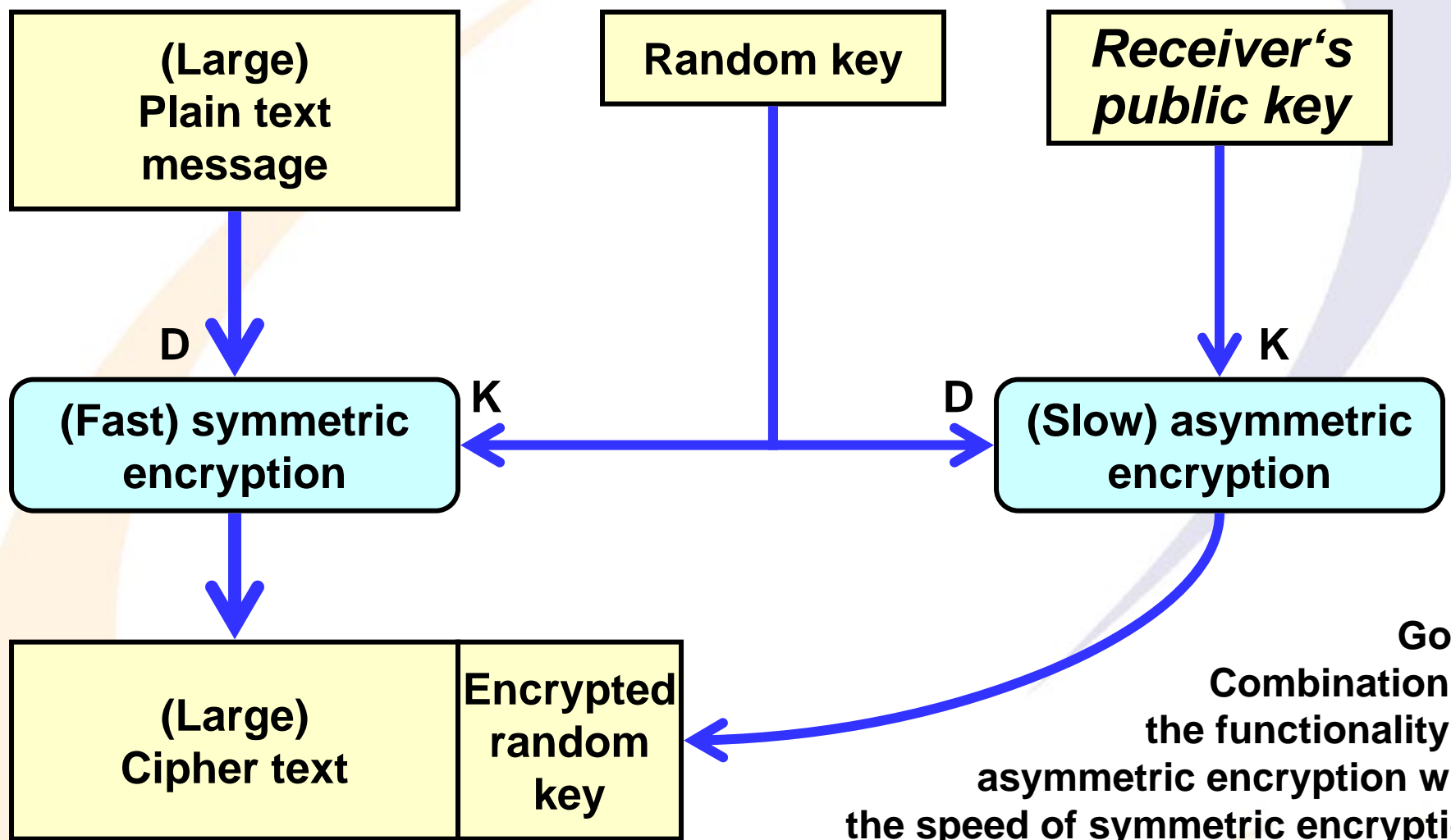
Asymmetric cryptography



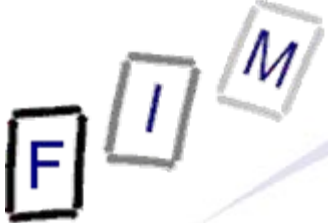
- One part (private) of the key is used for decryption/signature
 - A encrypted to B: B's private key is used to decrypt
 - A signed to B: A's private key is used to sign
- The other (public) is used for encryption/verification
 - A encrypted to B: B's public key is used to encrypt
 - A signed to B: A's public key is used to verify the signature
- The public key is available to everyone
 - Problem: Association "Key \leftrightarrow Person" must be ensured



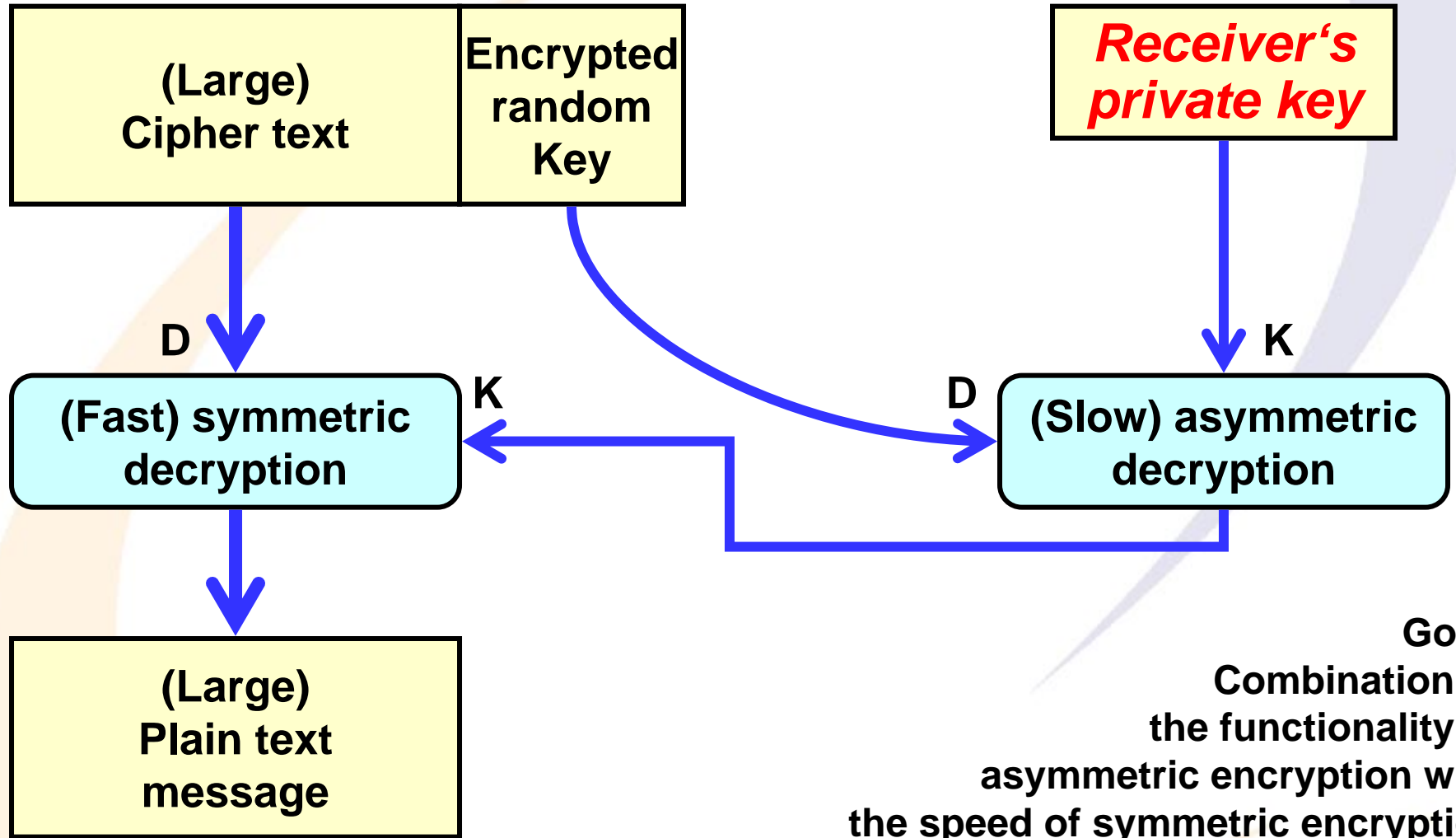
Combining Symmetric & Asymmetric Encryption (1)



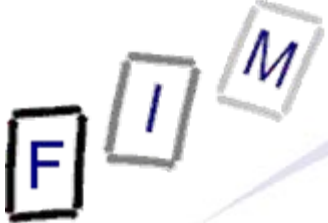
Goal:
Combination of the functionality of asymmetric encryption with the speed of symmetric encryption



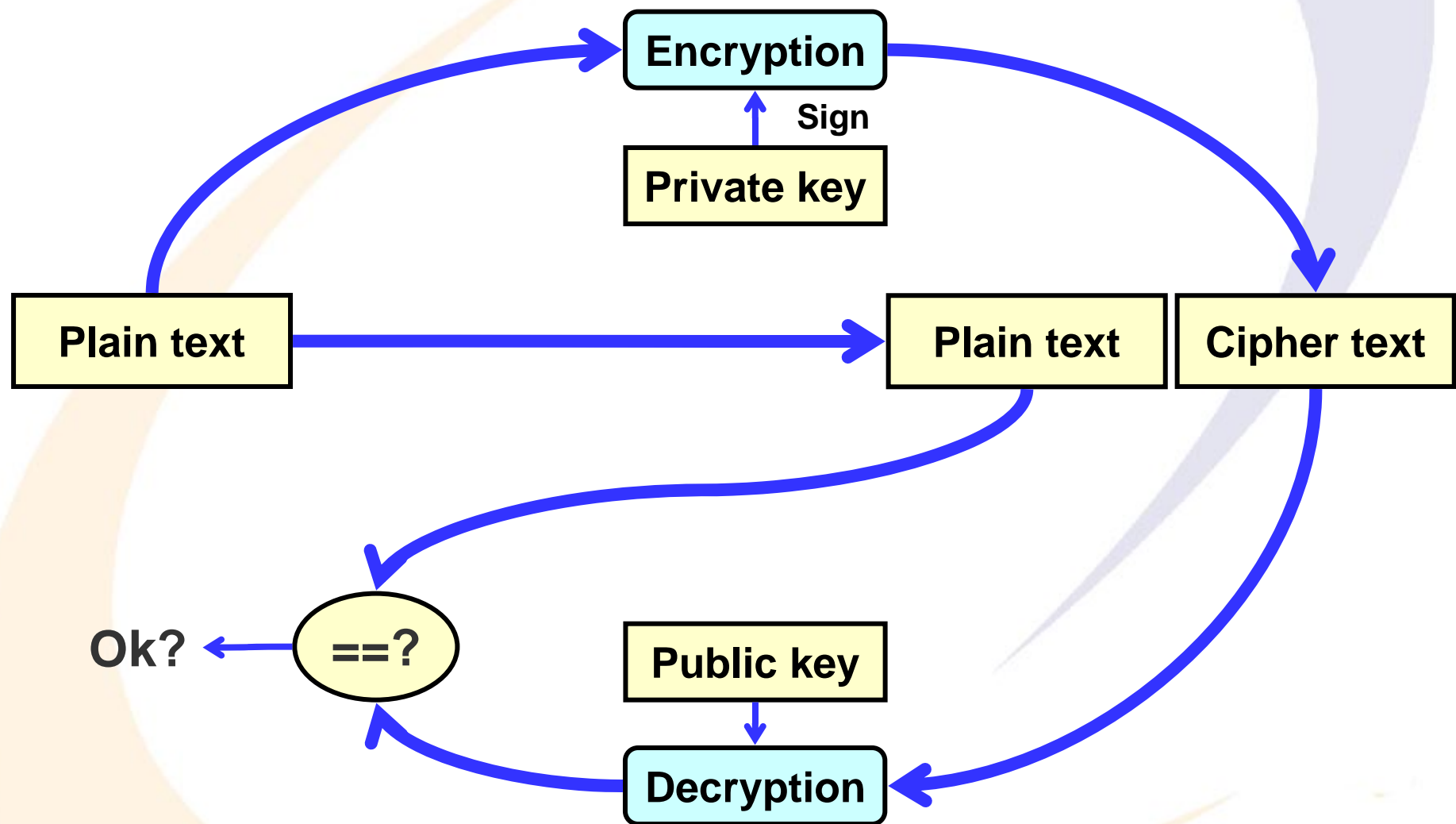
Combining Symmetric & Asymmetric Encryption (2)



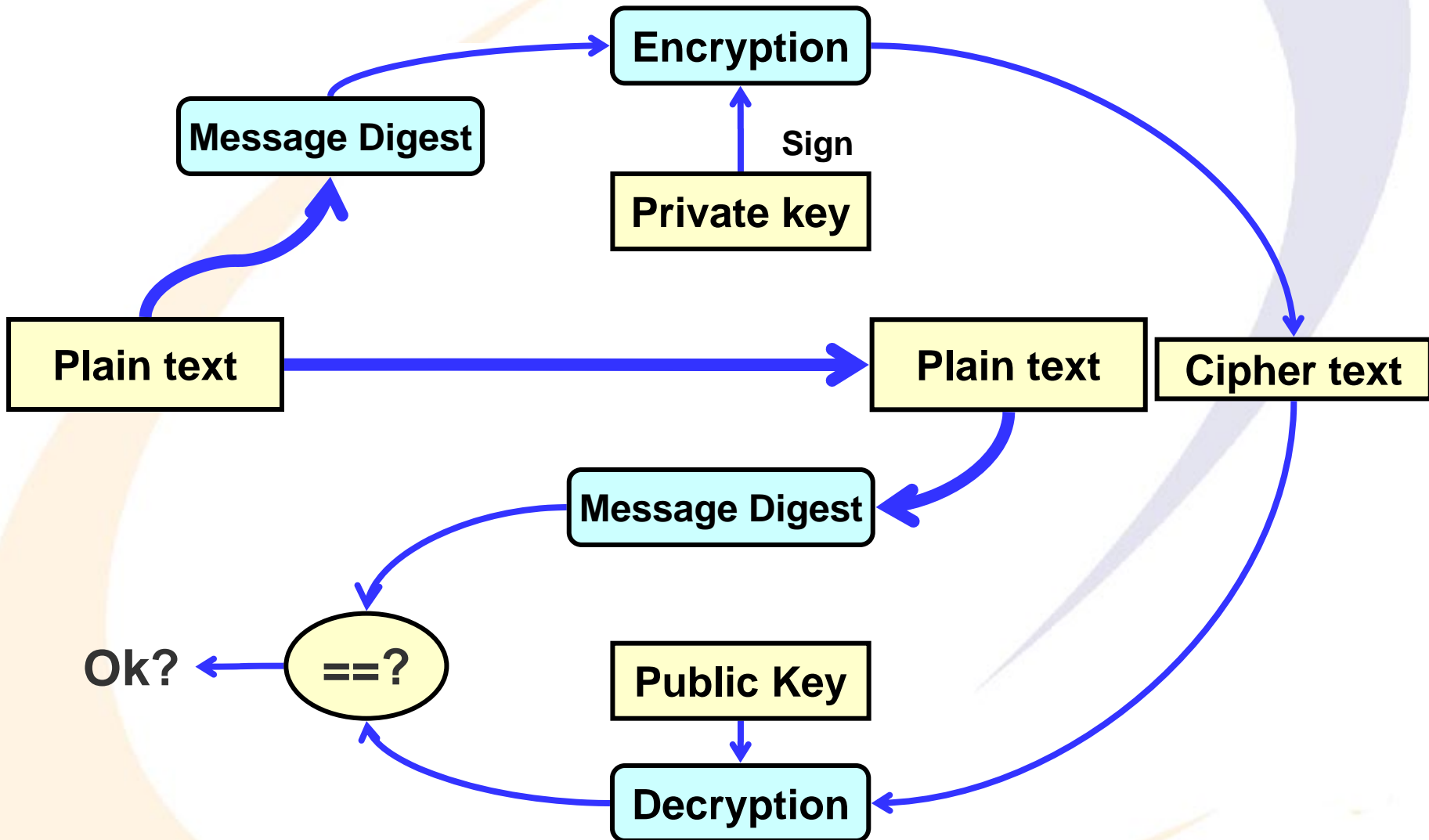
Goal:
Combination of the functionality of asymmetric encryption with the speed of symmetric encryption



Sign: Encryption with private key + ...



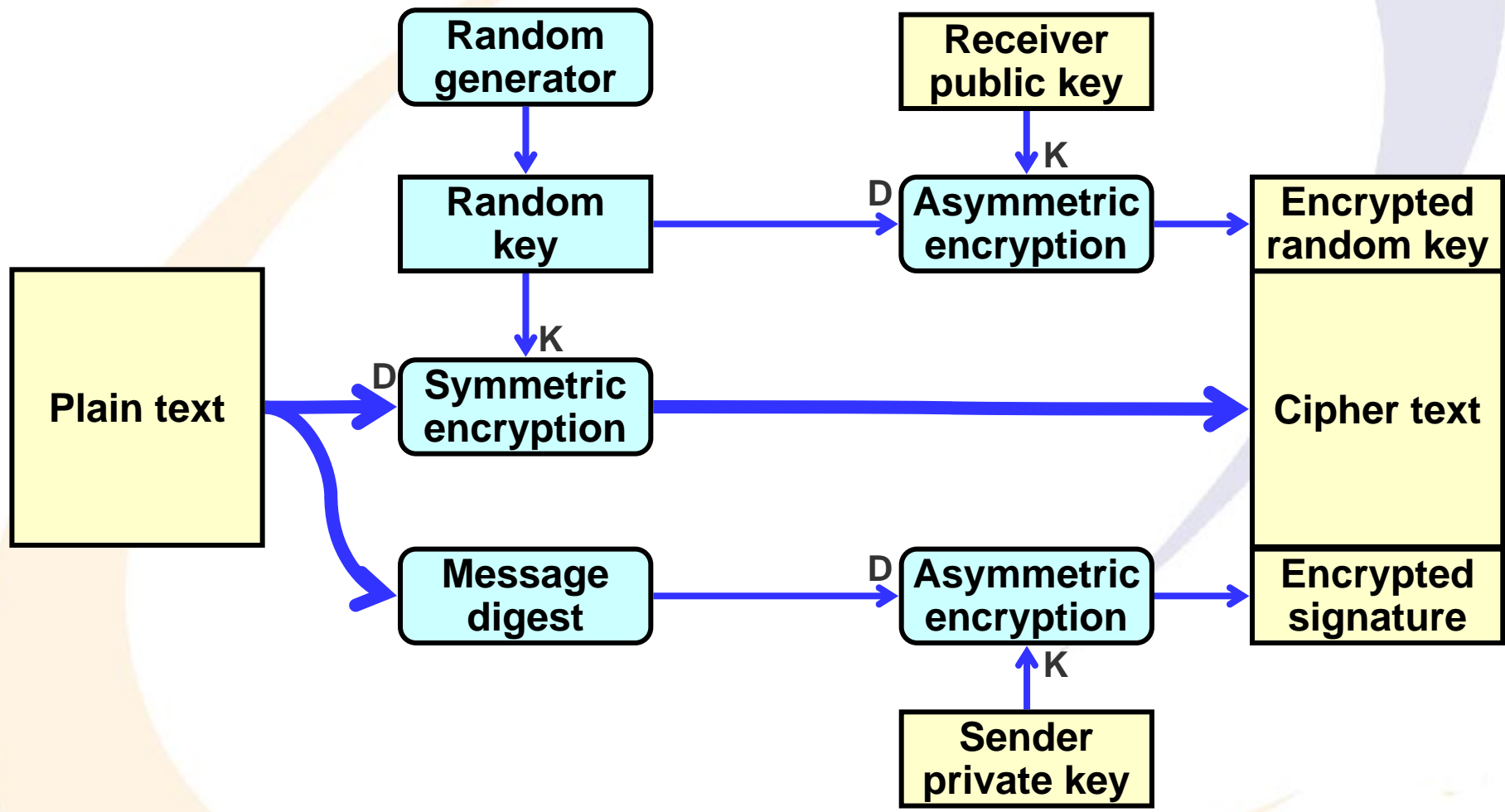
Check: Decrypt with public key + compare





Signature & Encryption

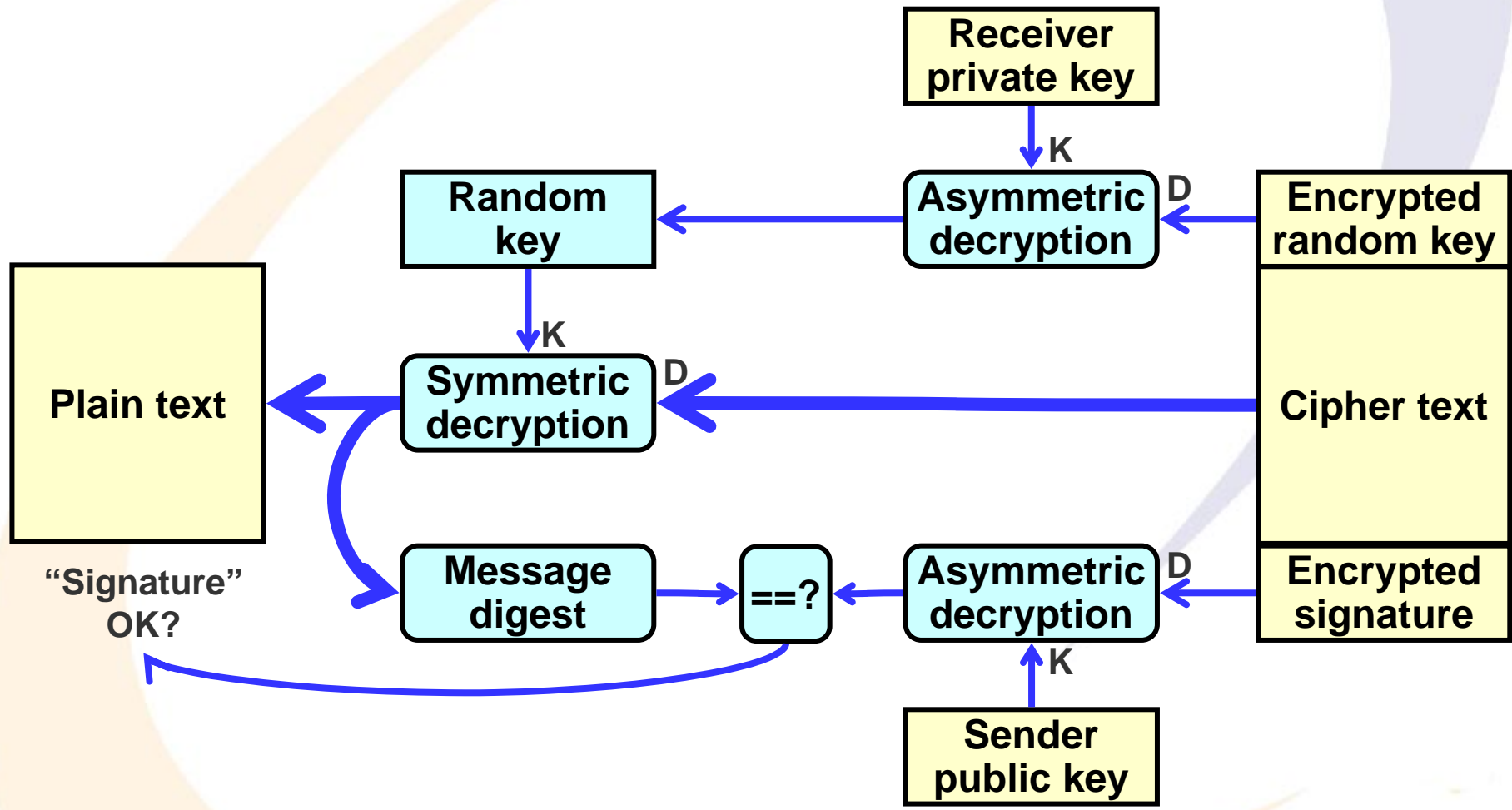
Sender





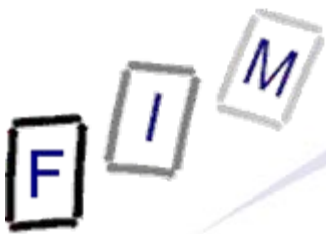
Signature & Decryption

Receiver





- Symmetric:
 - DES/3DES: 56/112 Bit; DES is now insecure; 3DES sufficient for commercial use (frequent key changes recommended)
 - AES (=Rijndael): New "standard" algorithm; different key sizes
- Asymmetric:
 - RSA: Classic asymmetric cipher (rather slow)
 - » Arbitrary key size (≥ 1024 recommended); no longer patented!
 - DSA: Only signatures supported, no encryption possible
- Hash:
 - SHA-1, RIPEMD-160: 160 Bit; SHA-2: 224-512 Bit
 - » SHA-1: Deemed to be not quite secure anymore
 - MD5: 128 Bit (not recommended any more; insecure)
- Other:
 - Diffie-Hellman: Key agreement without previous knowledge
 - » Generates a shared secret key



Strength of algorithms for the future

- The necessary key length is not static:
 - Faster computers
 - Advances in mathematics
 - New attacks (most dangerous of all!)
- Decision for length must incorporate:
 - Time/power required for en-/decryption
 - » See e.g. smartcards/RFID (computing and electrical power)!
 - Degree of security (=amount of money required for breaking)
 - Absolute time the calculated value should remain secure!
 - » Very often ignored!
 - » Guideline: For the next 15 years (values below: 2024)
 - Symmetric: ≈ 89 Bit
 - Asymmetric: RSA, ...: ≈ 2113 Bit; DSA: ≈ 157 Bit
 - Corresponds to a budget for an attack in 1 day of ≈ 732 million US\$

Source: Lenstra, A. K., Verheul, E. R.: Selecting Cryptographic Key Sizes. DuD 24 (2000), 166
Full article: <http://security.ece.orst.edu/koc/ece575/papers/cryptosizes.pdf>



Key exchange: Diffie-Hellman

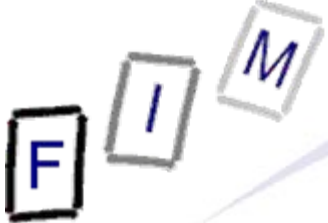
- Establishing a shared secret without prior knowledge over an insecure communication channel
 - **Note: Vulnerable to man-in-the-middle attacks!**
 - » Attacker establishes shared secrets with both parties independently → Some method of authentication is needed
- Incorporated in numerous protocols as a part
- Idea: One-way function (easy to compute, hard to invert)
 - **Here: Given $x^y \bmod p$, x , p → Calculate y**
 - » **Exponentiation: Simple; Discrete logarithm: Very hard**
- A: Selects a , p , g (p =prime number)
- B: Select b , and obtains p and g
- $A \rightarrow B$: $g^a \bmod p$ $B \rightarrow A$: $g^b \bmod p$
- A calculates: $(g^b \bmod p)^a \bmod p = \text{SECRET}$
- B calculates: $(g^a \bmod p)^b \bmod p = \text{SECRET}$



- Symmetric encryption algorithm with 56 Bit keysize
 - Now seen as insecure because of short key length
 - Specifically secure against a much later published attack
 - » Differential cryptanalysis → Was already known but kept secret!
 - Currently attacks with brute force possible
- Superseded by 3DES and AES
 - Triple-DES: $\text{Encrypt}(\text{key1}, \text{Decrypt}(\text{key2}, \text{Encrypt}(\text{key3})))$
 - » Because of a special attack, security is only 112 Bits!
- Because of its design DES is fast to implement in hardware, but slow to implement in software
- Basic idea:
 - Permutations, Expansion, Substitution, Permutation
 - Encryption and decryption are identical (only: key reversed)



- Replacement for DES – Symmetric encryption
 - Key length: 128, 192 or 256 Bits
 - 192, 256 Bits are allowed for US classification "Top secret"
- Fast to implement in hard- and software
 - Now widely used in various devices and software
- No known weaknesses of the algorithm
 - Note: Implementations may still suffer from problems
 - » Example: Side channel attacks, like timing encryption steps, measuring power usage, ...
- Basic idea:
 - Expansion, Substitution, Transposition, Mixing



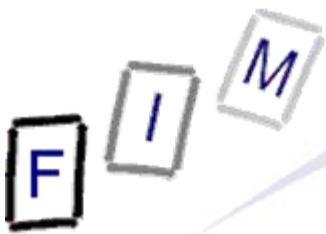
- First public-key algorithm suitable for signing and encryption
 - Still secure, if long enough keys are used!
- Basic idea:
 - Choose two very large prime numbers and multiply them
 - » Factorization of this number is very hard
 - From these numbers a private and a public key are derived
- Some mathematical weaknesses exist:
 - Use a random padding, so each encryption of the same text produces different output
 - The same key should not be used for signing and encryption
 - Prime numbers are usually only checked probabilistically
 - Good random number generators are needed
- Key length: 1024 Bit might be broken in the near future
 - Recommendation: Use 2048 Bit key



- MD5 = Message Digest algorithm 5
 - Hash length: 128 Bit
 - » Typically: 32 characters (hexadecimal encoding)
 - Very widely used
- Attention: Several flaws are known!
 - Collisions (= 2 texts with identical hash) can be constructed
 - Interesting: MD5 is used in many webpages → Google can be used as a lookup tool!
- Often used for storing password: "store MD5(pwd)"
 - Use at least "salting"
 - » Store x , MD5($x || \text{pwd}$) with a new random x for each account!
 - Or: "Better" algorithms, i.e. requiring more time to calculate
- Function:
 - Cut message up into 512 Byte blocks (use padding for last)
 - Based on addition, shifting, non-linear function

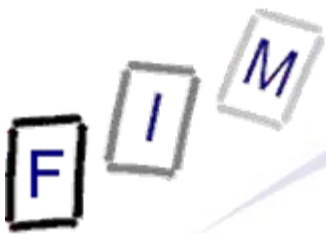


- SHA-1 = Secure Hash Algorithm
 - SHA-1: 160 Bits
 - SHA-2: 224, 256, 384 or 512 Bits (Individually: SHA-224, ...)
- Not completely secure any more!
 - No known attacks, but mathematics has proved weaknesses
 - Original strength: 80 Bit (birthday paradox)
 - » = 1/2 length; maximum value possible → 2^{80} tries for a collision
 - Current state: 2^{63} tries
 - » Just barely useful for very-large-budget organizations (NSA)
- Function: Similar to MD5, but with different configuration
- SHA-2 uses different algorithms
 - No known weaknesses, but not much investigation either!



Environmental components

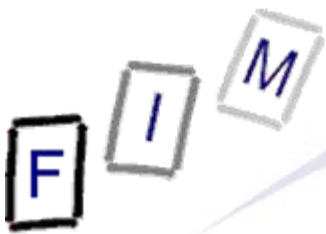
- Encryption algorithms are not **all** there is, to be secure
- Many other elements must be taken care of:
 - **Technical "surroundings":**
 - » Secure viewer: Showing exactly the content to sign and not something different
 - » Secure transmission of codes/PINs from chipcards/terminals to the CPU actually calculating the signatures or the hashcode in reverse when signing takes place on the card/terminal
 - » Physical access control/restrictions?
 - » Side channels: Power, temperature, timing, cache access, ...
 - **Organizational issues:**
 - » Who knows the encryption keys and where are these stored?
 - » How to get at them in case of illness/dismissal?
 - » Who is allowed to do what? Does the equipment support these different security levels?
 - » Securing keys/certificates etc. against loss



- Public keys must be connected to a certain individual/device
 - Everyone can use/create a key, but how do you know that the person holding the private key is actually "Donald Duck" (or a certain person using this pseudonym)?
 - "Someone" guarantees, that these two belong together

Certificates connect a public key to a name

- Certificates may contain other information
 - E.g. server certificates may contain the administrator's E-Mail
 - Personal certificates may contain restrictions or special permissions/empowerments
 - » May act on behalf of a company, transaction restrictions etc.
- Certificates are signed too, so nobody can tamper with them
 - Chicken-egg problem: Who signed the certificate?
 - » Pre-shared "master" certificate/Public Key Infrastructure (PKI)



Certificate content

- Currently only certificates of type X.509 are of importance
 - Several versions available; current one: 3 → X509v3
 - Standard is not too clear
 - » Certificates from one vendor might be incompatible with those from another vendor or with some software
 - » Special problem: What data, which form, which "schema"
- No problem:
 - Public key including algorithm
 - Issuer: Who "guarantees" for the association key ↔ name
 - Version, serial number, validity, unique IDs
- Problems:
 - Subject (=associated name): Different elements (E-Mail, additional/missing parts, ...)
 - Extensions: Key usage, CRL distribution, constraints, etc.

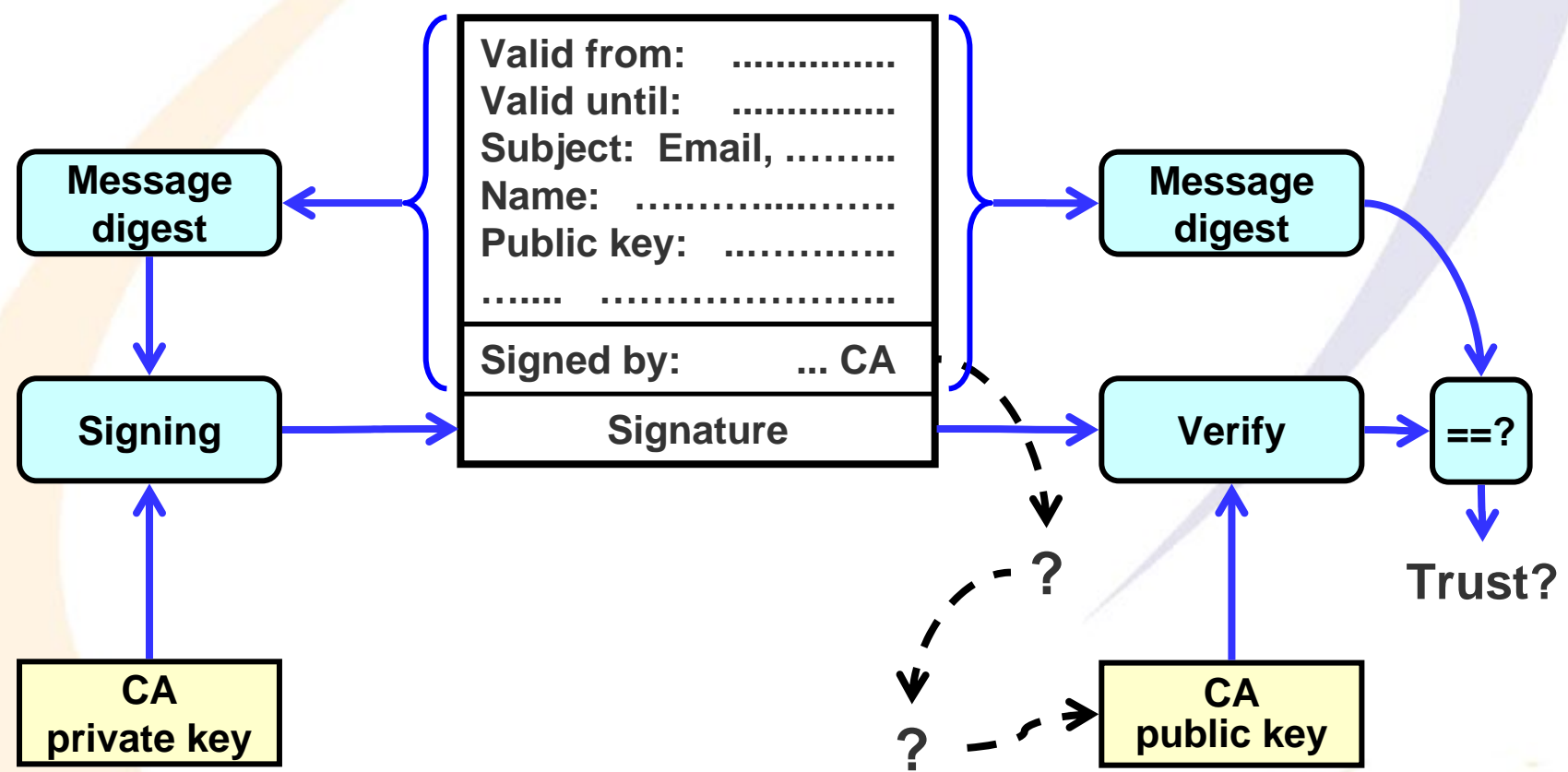


Certificate

Certification Authority "CA"

Certificate

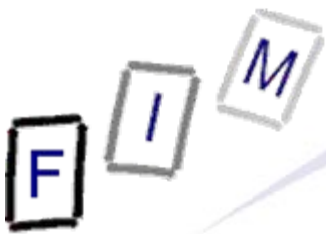
Verification of the certificate





Public Key Infrastructure (PKI)

- Who guarantees, that the certificate is "correct"?
 - » I.e. that the key belongs to exactly this person and that this person was securely identify (and not some impostor)
 - The issuer through his signature of the certificate
 - Who guarantees, that this signature is "correct"?
 - » ...
 - ...
- Solution: The "top-level" certificate is self-signed
 - Key used for signing is the one for the public key contained
 - This certificate you "just have to trust"
 - » Obtained from a secure source, verified (e.g. fingerprint), ...
 - Can also be "cross-certified": One top-level certificate is used to sign another top-level certificate and in reverse
 - » Good for few CAs (otherwise: $O(N^2)$!)



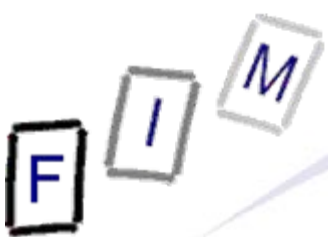
Encryption for the WWW

- When transmitting sensitive information on the Web, the communication should be encrypted
 - Examples: Credit card numbers, company-internal forms, ...
- Currently one method is widely used: TLS
 - Secure Socket Layer: A general solution for encrypted TCP traffic; most common use with http (⇒https; NOT: shttp)
 - » Option to use http and switch internally to TLS (=STARTTLS)!
 - TLS (Transport Layer Security): SSL successor, very similar
- TLS provides:
 - Encrypted communication: Eavesdropping impossible
 - » Depends on the actual algorithm/keylength used
 - » Uses symmetric cryptography for speed; numbers against replay
 - » Asymmetric cryptography used for key exchange
 - (Mutual) authentication by asym. cryptography supported
 - Configuration very important (algorithms, cert. storage, ...)



Alternatives: Pre-shared keys

- Only suitable for very small group of partners communicating
 - See VPN later; especially VPN tunnels!
- Keys must be exchanged over a trusted channel
 - I.e. **NOT** over the channel used for communicating!
- Protocols must use "Challenge-Response": The key may never be sent in clear!
 - » Before you don't know who is on the other side ...
 - Common way: Random value sent, hashed with secret key, sent back, compared to expected response
 - » No eavesdropper/man-in-the-middle can retrieve the key from it
- Not possible with SSL or TLS!
- Advantage: Usually very simple to manage
 - Agree on a keyphrase, telephone call ⇒ works!
 - » No additional infrastructure needed (PKI, CRL, etc.)

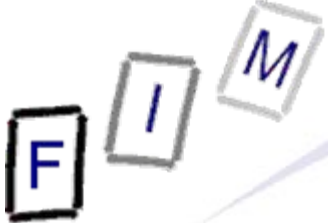


- Similar to PKI, but distributed model
 - Signing someone other's keys to certify, that the association is correct; diverse servers for storing keys and signatures
- Based on transitivity of trust (=the signatures):
 - A trusts B, B trusts C, C trusts D \Rightarrow A trusts D
- Not possible with SSL!
 - Uses different certificate format
 - Currently mainly used for E-Mails
- Advantage: No single point of failure
- Problem: No guaranteed decision
 - Perhaps just no trusted connection exists; still valid & correct!
 - CA's are possible, but not necessary
 - System reliable only, if keys signed by many people
 - Such people are not found easily everywhere

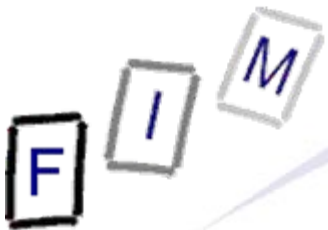


"Official" certificates: Advantages / Disadvantages

- + No warning messages for browsers
 - + Identity of person/company verified accurately
 - » More trust than a self-signed certificate
 - + Browser interoperability (creating a "good" one is not easy!)
 - + Key length issues, etc. are taken care of
 - + Provides reliable directory servers and CRL/OCSP services
 - Costs money (and expires regularly, requiring a new one!)
 - At least one free provider now available (<http://cert.startcom.org/>)!
 - May take some time to obtain (depending on CA/location)
 - Guarantees for **content** are small or non-existing
- Result:
 - Public website: Indispensable (browser warning)
 - Private/internal use: Very few reasons
 - » Except: Large companies, where managing secure and available directories and CRLs are difficult!



- VPN = Virtual Private Network
 - A private network across a public medium
 - Replacement of leased lines by encrypted/authenticated communication using the "ordinary" and common internet
 - » In the generic case, it can also be any kind of other communication system, but the internet is by far the most important one!
- Especially important for mobile workers
 - Always "virtually" located in the home network
 - » Telephone (VoIP): Same number same functionality, ...
 - » Server access: E-Mail, file servers etc.
 - » Internal applications available
 - Can move from place to place freely
- Other application: Branch offices
 - The internet serves as the company backbone



VPNs: Advantages

- Transparent for users (apart from establishing perhaps)
 - User virtually sits on the other end of the tunnel
- Obviates the need for a firewall
 - Everything is encrypted and authenticated
 - » Filtering would be impossible anyway
 - But does **NOT** secure against "internal" attacks
 - » **I**nternet is protected against, **I**ntranet must be secure itself!
 - Especially important for mobile workers: The laptop is virtually inside the company, but may have been connected also to other networks and is therefore possible infected, insecure, ...
 - Does **NOT** apply in "split" configurations
 - » Some traffic is sent through the tunnel (e.g. file server access)
 - » Some traffic is sent to the Internet directly (e.g. webbrowser)
 - Practice: VPN connections are in a kind of "DMZ"
- Easy to set up if basic configuration exists (i.e. 2nd, 3rd, ...)



VPNs: Problems

- Traffic can no longer be compressed
 - Must happen before or at the tunnel endpoint
 - » Modern devices support this
- No QoS (as often available with leased lines)
 - The Internet only does what it can
- Sometimes difficult to set up; interoperability difficult
 - Becomes better with IPSec
 - Much easier with TLS-based VPNs
- Powerful hardware needed for encrypting larger bandwidth
 - Dedicated devices, "VPN concentrators", ...
- Overhead; more bandwidth required
 - This is today usually only a small problem!
- Data is physically outside: Not necessarily secured as well!



- Using VPNs, SSL, digital signatures is nice (and necessary!), but does not solve all problems:
 - Denial of Service
 - Endpoint security (storing those credit card numbers)
 - Users: Security is cumbersome and therefore circumvented
 - Cryptography is only as secure as the key storage
 - » Who uses really good passwords/passphrases?
 - » How is the "backup" of the password organized (bank safe)?
 - Physical security? Social engineering? Internal attacks?
- But security is also not self-serving:
 - Value of goods to be secured vs. cost of protection

A holistic view is required for encompassing security!

F I M

Questions?

Thank you for your attention!