Cyber Physical System Security SC4015/CE/CZ4055

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Contents

Discussions from Last Week

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Automata and *Examples*

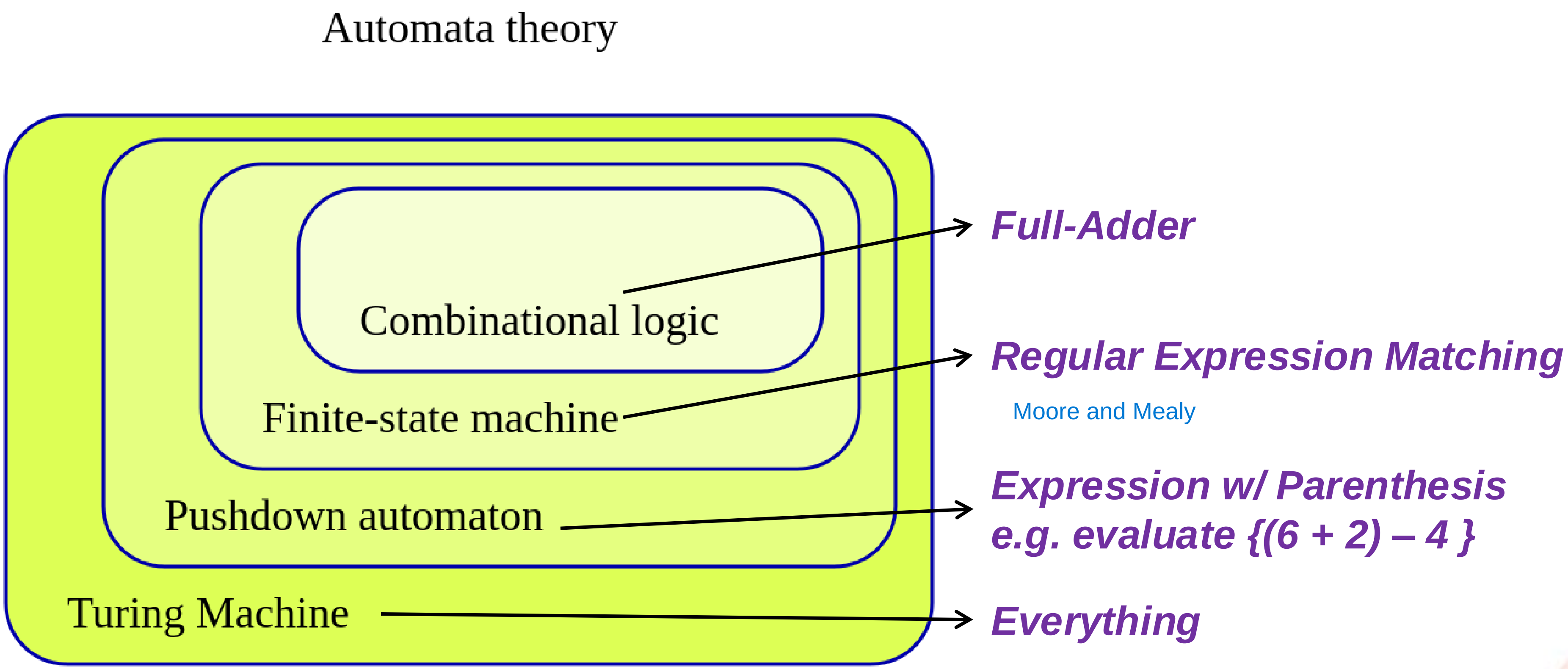

Image source: wikipedia

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Trusted Service Manager

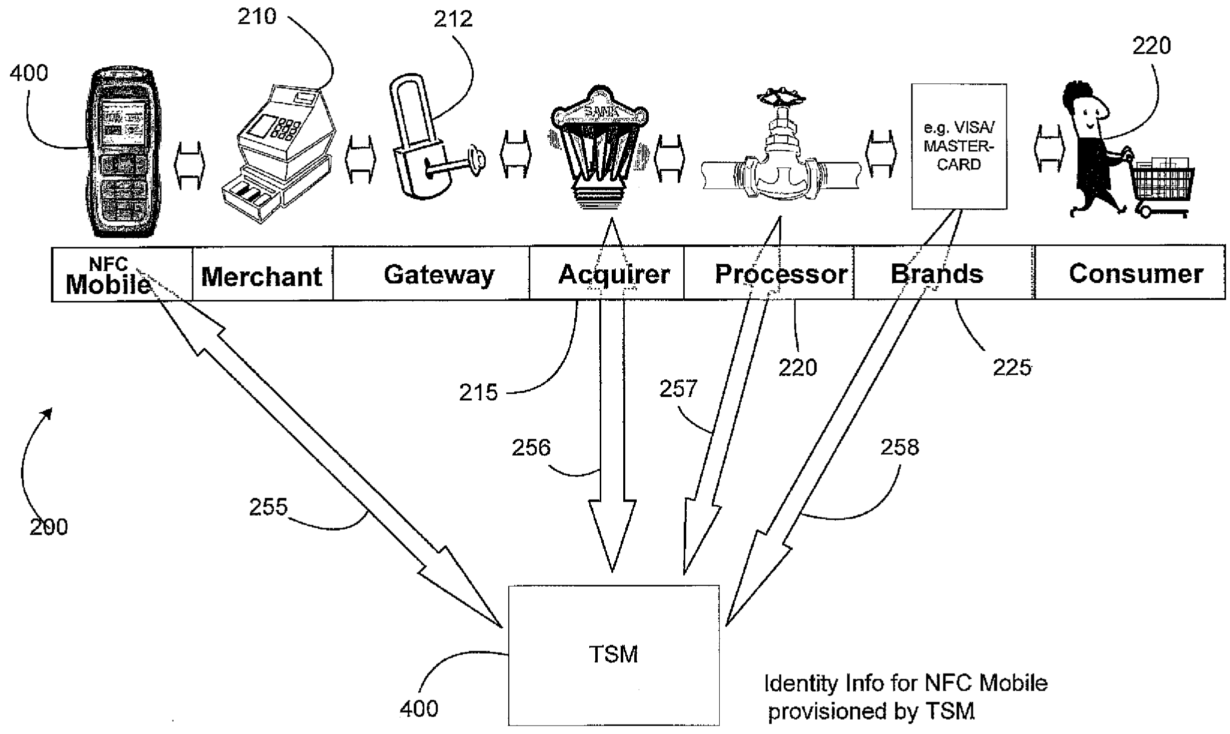

FIG. 2

Image source: Paypal patent US8417643B2

Trusted Service Manager

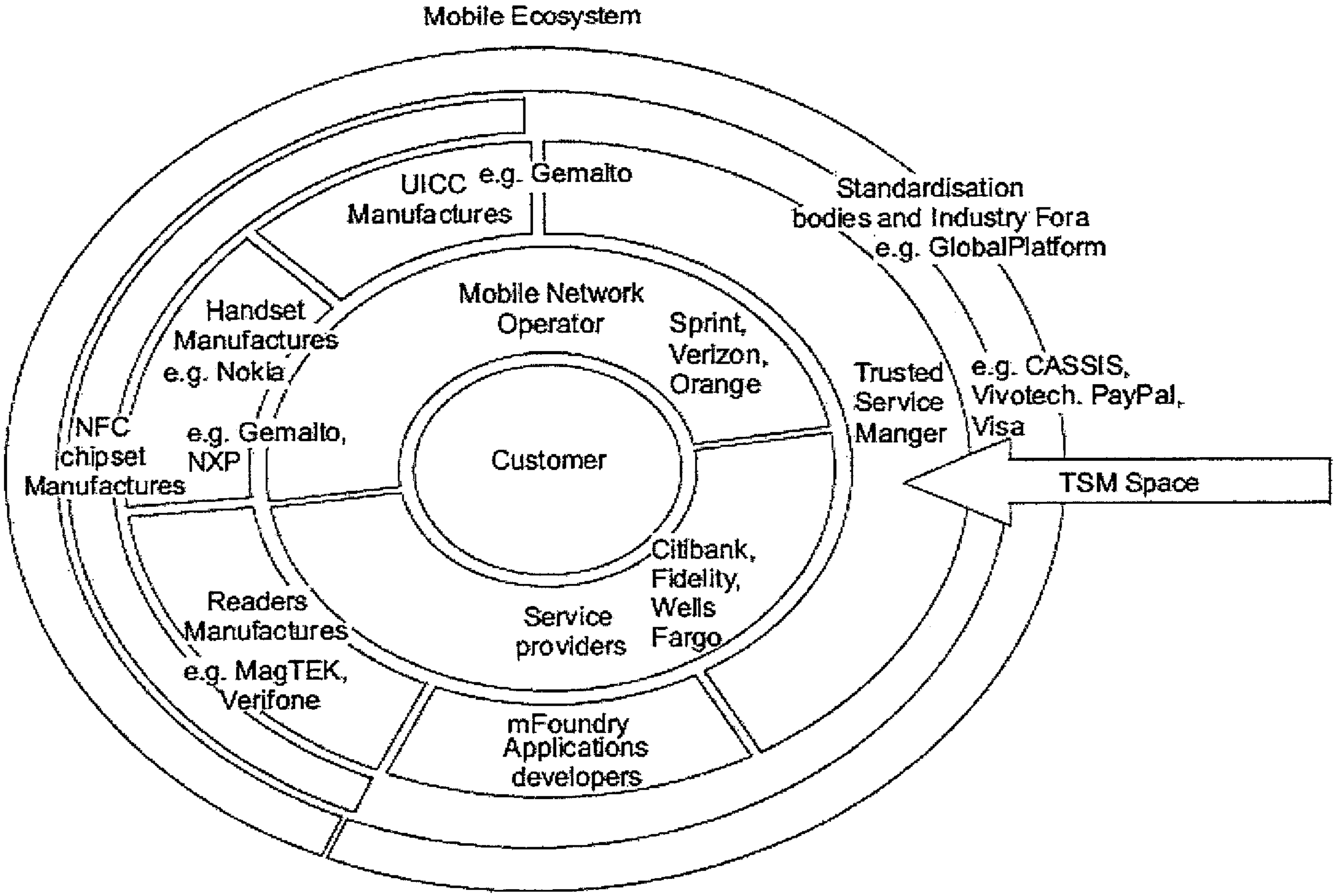

FIG. 1

Image source: Paypal patent US8417643B2

Trusted Service Manager: Tasks

1. **User registration**: Corresponding to a bank
2. **Managing Digital Certificates**: User identity
3. **Authentication** and **Verification**: Transactions of the mobile wallet with a payment terminal

- The above services are delivered using the underlying platform, in particular
  - **SE**: Storage of keys, passwords, identity
  - **Secure Communication**: NFC
  - **TEE**: Secure Microprocessor for providing security services (e.g., encryption, authentication)

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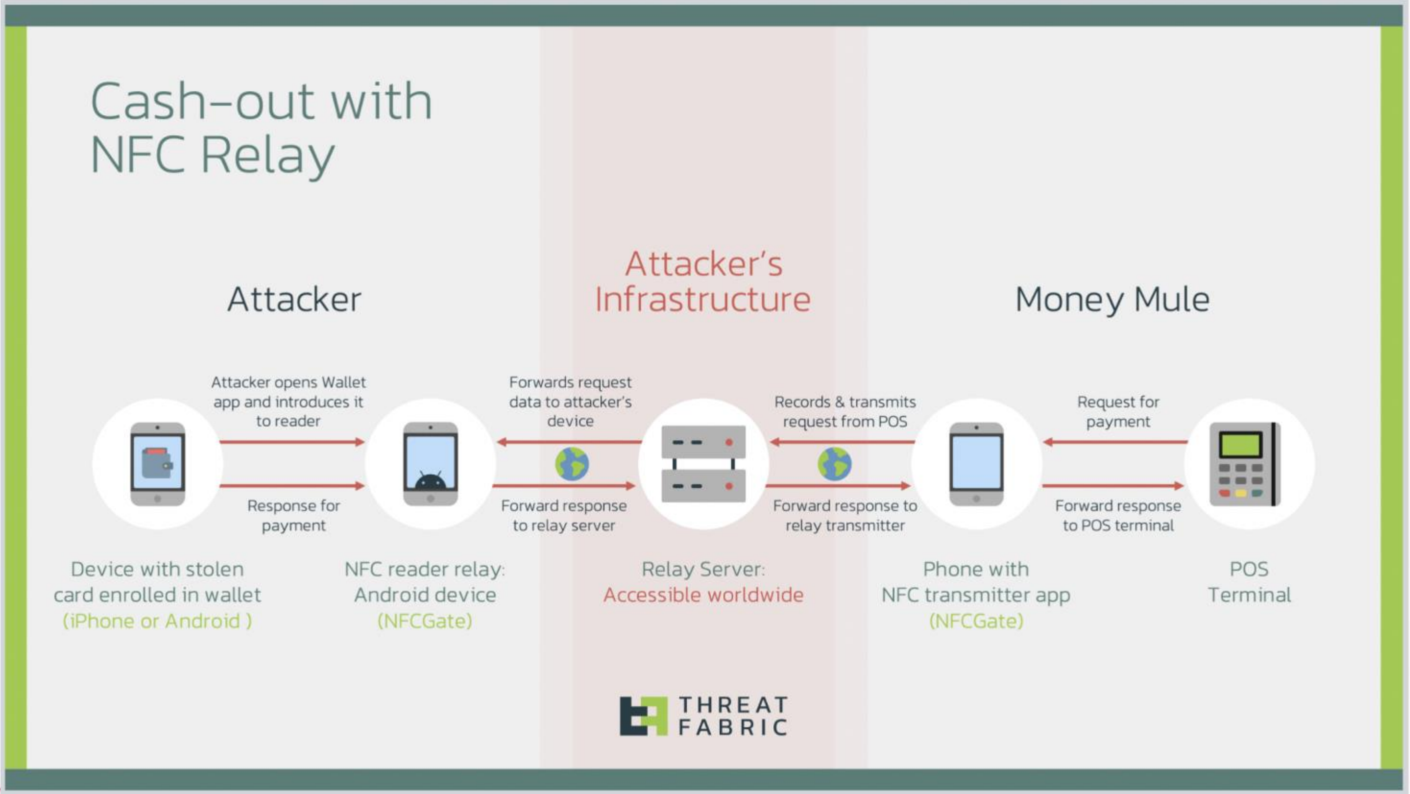
NFC Security *(1/2)*

- NFCGate: Android toolkit for NFC traffic (and security) analysis
- Used by hackers to steal money



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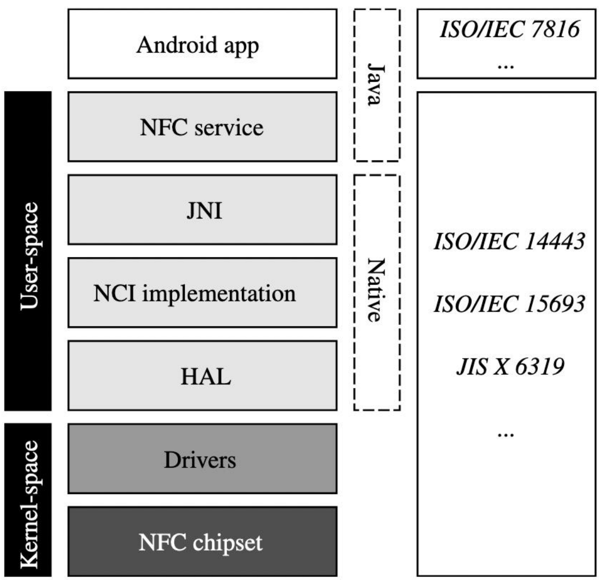
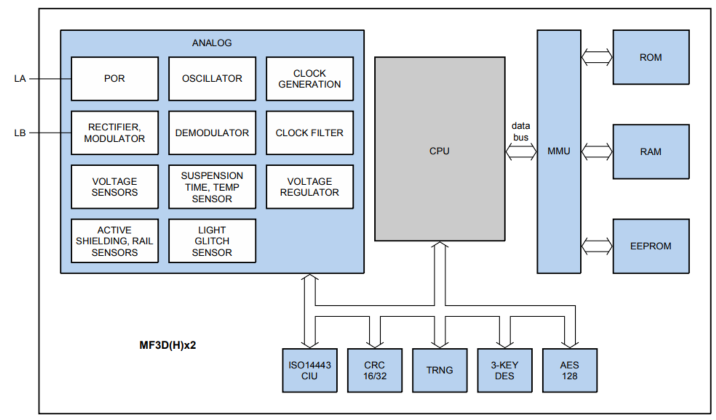
S. Klee et al, "NFCGate: Opening the Door for NFC Security Research with a Smartphone-Based Toolkit", Usenix 2020
https://thehackernews.com/2024/11/ghost-tap-hackers-exploiting-nfcgate-to.html
https://github.com/nfcgate/nfcgate/blob/v2/doc/Compatibility.md

NFC Security *(2/2)*

- Through *Java symbolic hooks* → from other applications running in the background of the same platform
- Through *native instruction hooks* → alter the underlying platform behavior





Reverse engineer packets, as NFC IC is known

S. Klee et al, "NFCGate: Opening the Door for NFC Security Research with a Smartphone-Based Toolkit", Usenix 2020
https://thehackernews.com/2024/11/ghost-tap-hackers-exploiting-nfcgate-to.html
https://github.com/nfcgate/nfcgate/blob/v2/doc/Compatibility.md
https://github.com/nfc-tools/libfreefare

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NFC Security: Countermeasures

- Preventing Relay Attack

- Do not let *untrusted apps* running in the background
- Distance Bounding Protocols
  – To ensure that the endpoints of a communication are within a specified distance
- Mandatory Response Timeouts
  – To ensure that the reader ends a communication when there is a significant time-lag (introduced due to the relay)

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- *Security Triad*
- Cryptographic Primitives
- Discussion

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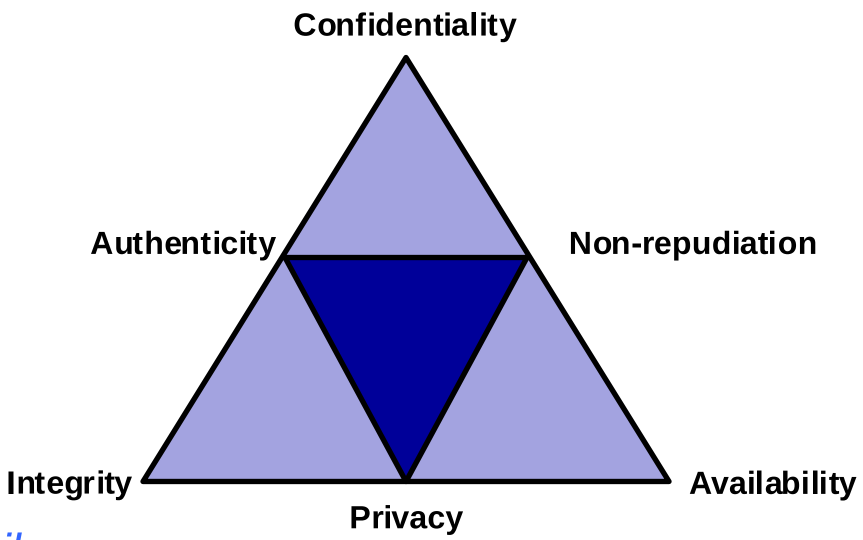
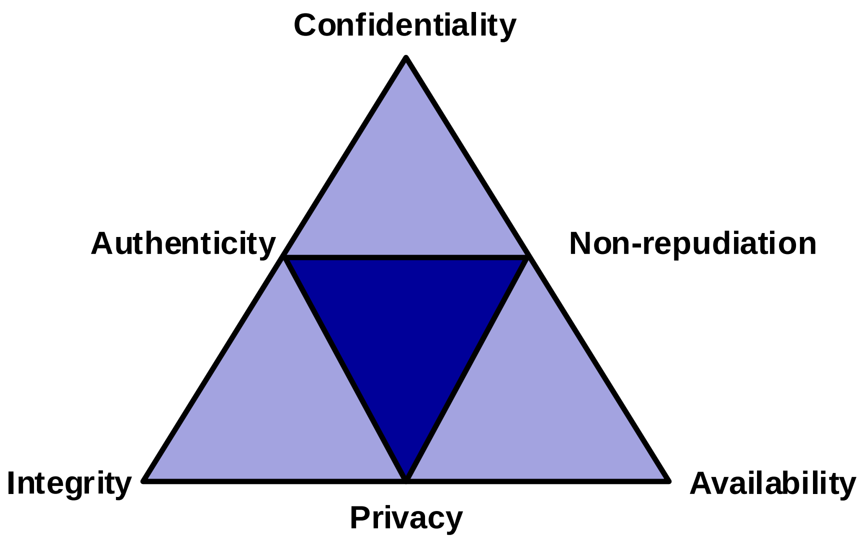
Security Triad

- IT security
  - Confidentiality
    - *Data is secured*
  - Integrity
    - *Data is trusted*
  - Availability
    - *Data is accessible*
  - Non-repudiation
    - *Service has a trusted audit-trail*
  - Authenticity
    - *Components have provable identity*
  - Privacy
    - *Service does not see customer activities*



Security Triad: Smart Card



- Smart Card security
  - Confidentiality: *Data is secured*
  - Integrity: *Data is trusted*
  - Availability: *Data is accessible*
  - Non-repudiation: *Service has a trusted audit-trail*
  - Authenticity: *Components have provable identity*
  - Privacy: *Service does not see customer data*

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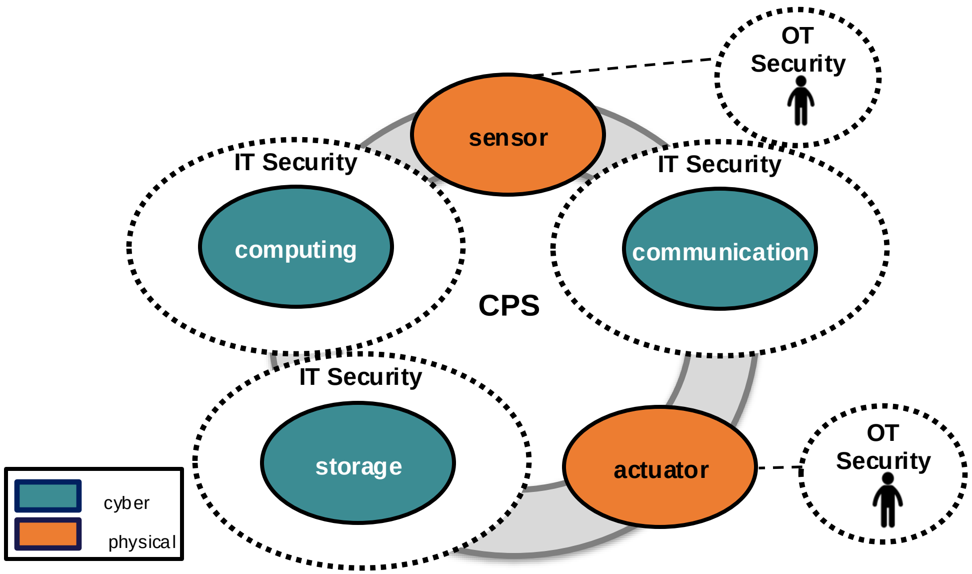
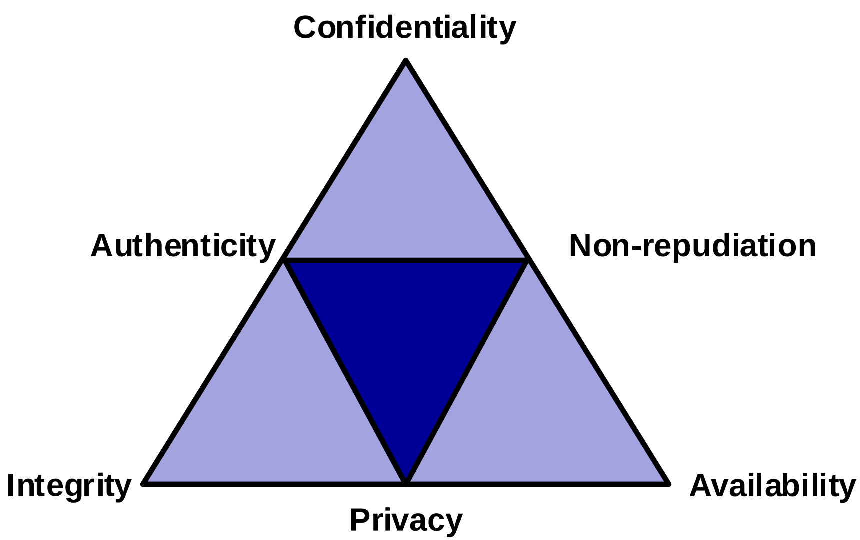
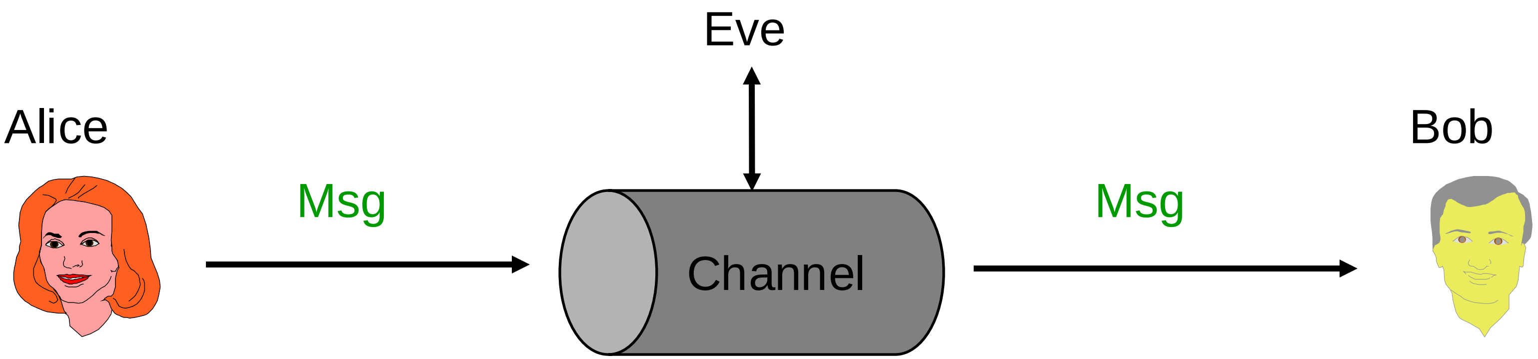
Security Triad for CPS



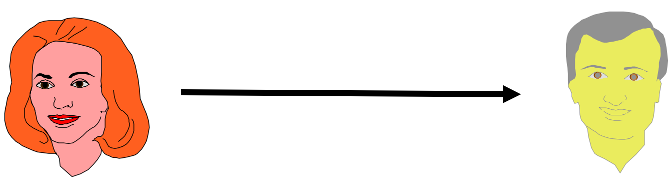


Network Security Model

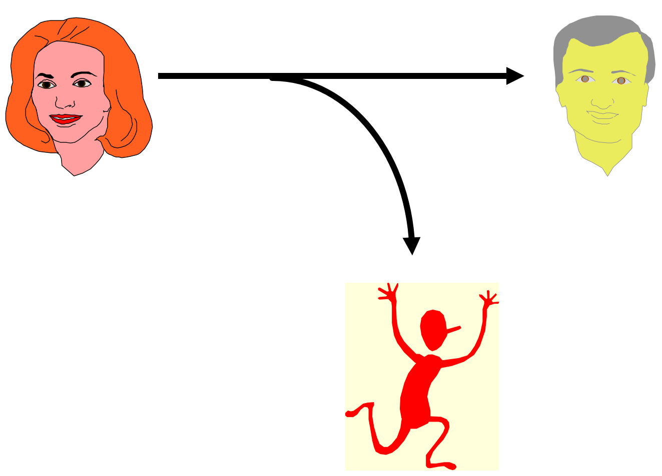


Confidentiality (Secrecy)

- Protect transmitted data
- Protect against traffic analysis



- **INTERCEPTION**
  Unauthorised party gains access to data



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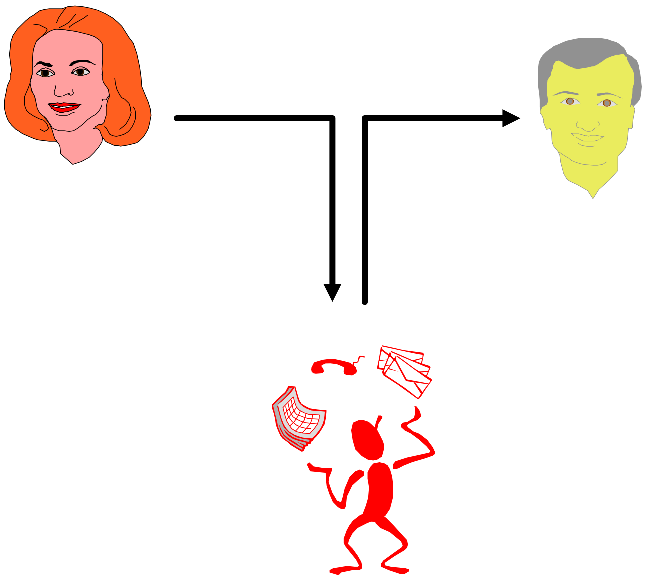
Integrity

- Message is received as sent
- Modification
- Also interested in replay, re-ordering, deletion, delay

- **MODIFICATION**
  Gain access and "tampers" with messages



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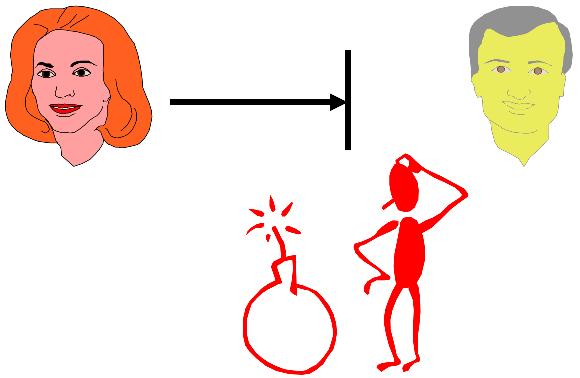
Availability

- Complete loss of availability
- Reduction/Degradation in availability

- **INTERRUPTION**
  Loss of communication (cut the cable)
- **DENIAL OF SERVICE**
  Noisy comms (physical noise, spurious messages)



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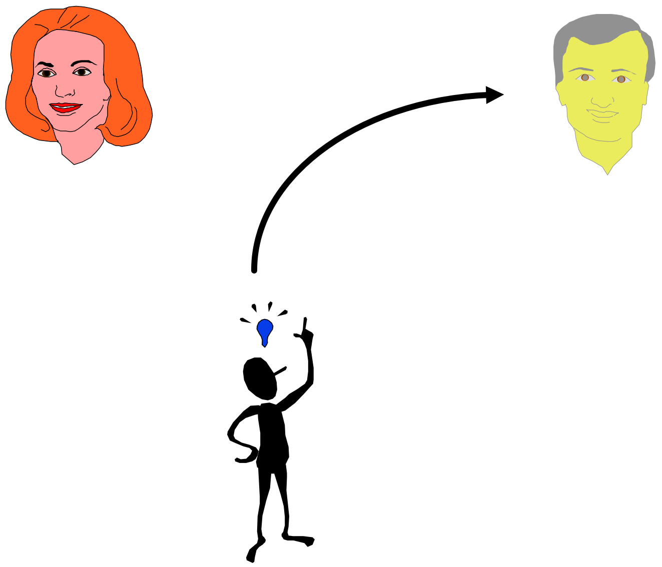
Authentication

- Assurance that message is from proper source
- Protect from third party masquerade

- **FABRICATION**
  Insertion of “counterfeit” messages



Non-repudiation

- Prevents parties from denying they sent or received a message; i.e. concerned with protecting against legitimate protocol participants, not with protection from external source
- Receiver can verify **and prove** who sent a message
- Sender can verify **and prove** who received a message

- **REPUDIATION ATTEMPT** Party anonymously publishes his or her message/key(s) and falsely claims that they were stolen.

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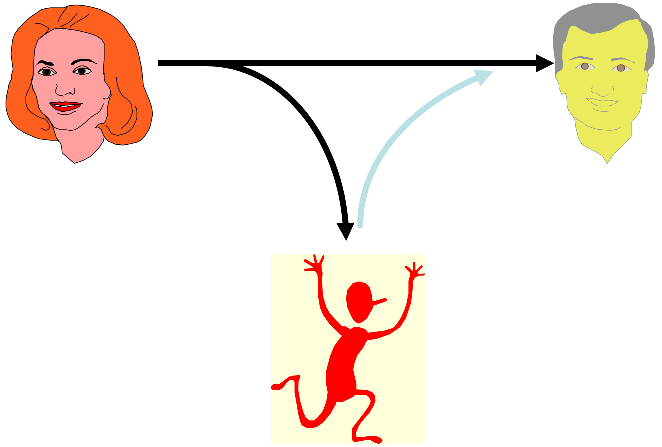
Privacy

- Limit and control access to host system/services
- Limit and control access to networks
- Authenticate each party so that access rights can be assigned
- More fine-grained solutions, e.g. Digital Rights Management

- **REPLAY**
  Record a legitimate message e.g. a login, and replay later



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- Security Triad
- *Cryptographic Primitives*
    - ***Private-Key Cryptography***
    - Hash Function, Message Authentication Code
    - Public-Key Cryptography
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Kerckhoffs's Principle

- An encryption scheme should be secure even if enemy knows everything about it except the key
  - Attacker knows all algorithms
- Do not rely on secrecy of the algorithms ("security by obscurity")

SYMMETRIC-KEY CRYPTOGRAPHY

Symmetric-key cryptography started thousands of years ago when people needed to exchange secrets (for example, in a war).

7th Century BC, Ancient Greece

Types of Symmetric-Key Cipher

- **Substitution Cipher**
  - A substitution cipher replaces one symbol with another.
  - Can be mono/poly-alphabetic

The following figures show two examples of a plaintext and its corresponding ciphertext. Which cipher is mono-alphabetic?

Plaintext: HELLO
Ciphertext: KHOOR

Plaintext: HELLO
Ciphertext: ABNZF

Types of Symmetric-Key Cipher *(contd.)*

- **Shift Cipher**
  - The shift cipher is also referred to as the Caesar cipher.

Use the shift cipher with key = 15 to encrypt the message “HELLO.”

Solution
We encrypt one character at a time. Each character is shifted 15 characters down. Letter H is encrypted to W. Letter E is encrypted to T. The first L is encrypted to A. The second L is also encrypted to A. And O is encrypted to D. The cipher text is WTAAD.

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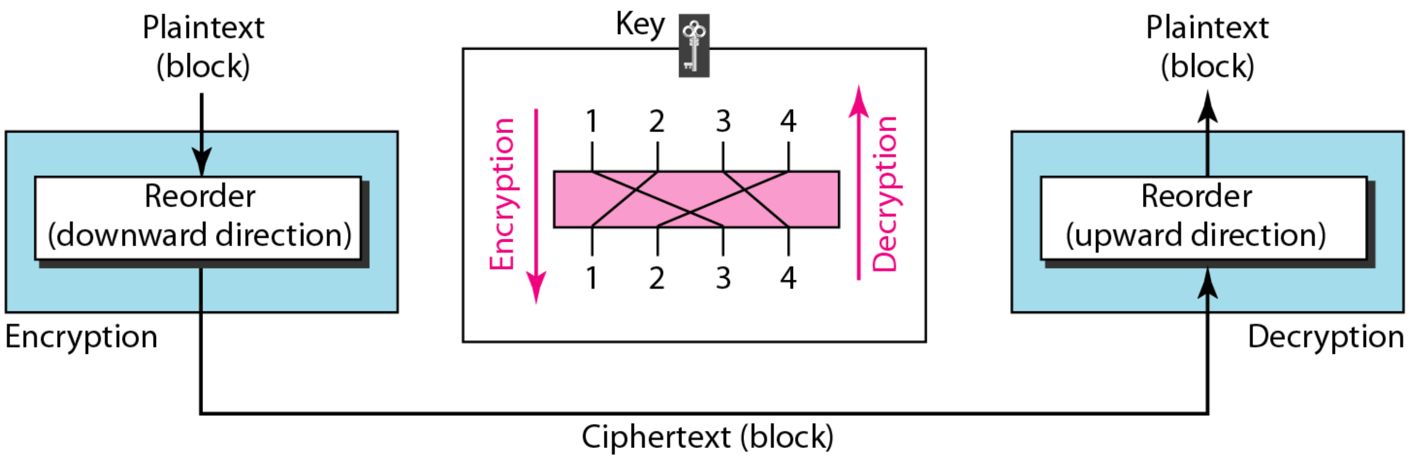
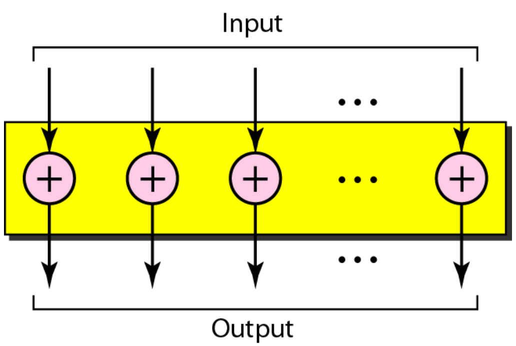
Types of Symmetric-Key Cipher *(contd.)*

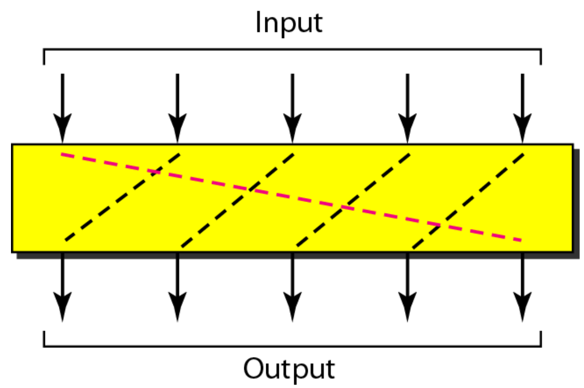
- **Transposition Cipher**
- A transposition cipher reorders (permutes) symbols in a block of symbols.



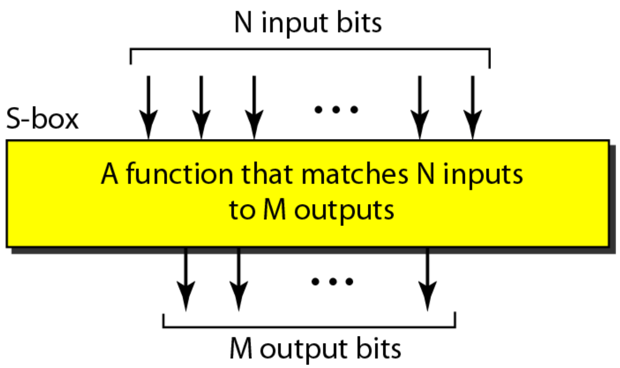
Components of Symmetric-Key Cipher



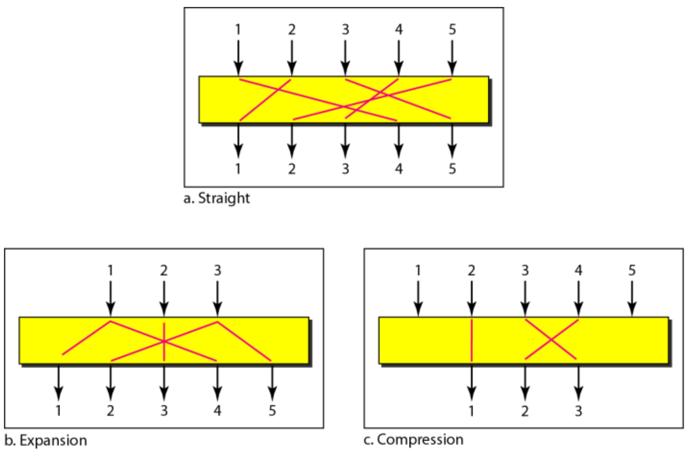
XOR substitution



Rotation substitution

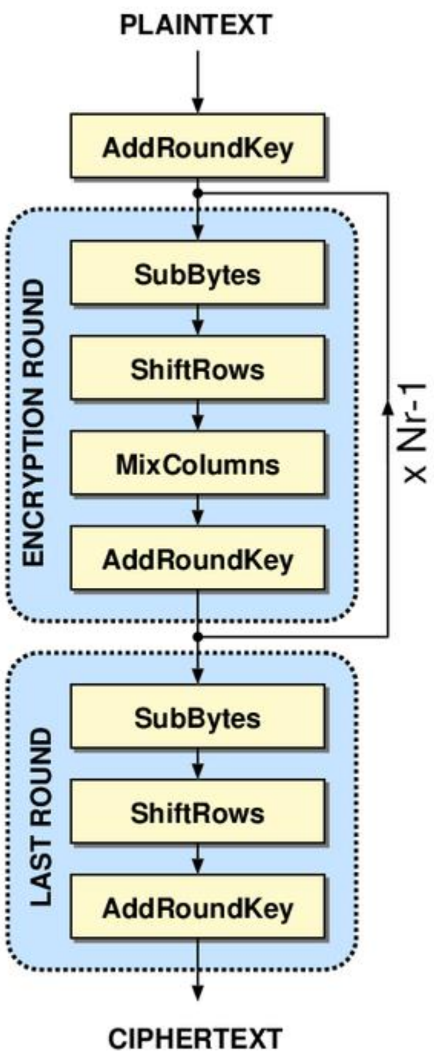


Substitution Box



Permutation Box

Block Cipher: AES



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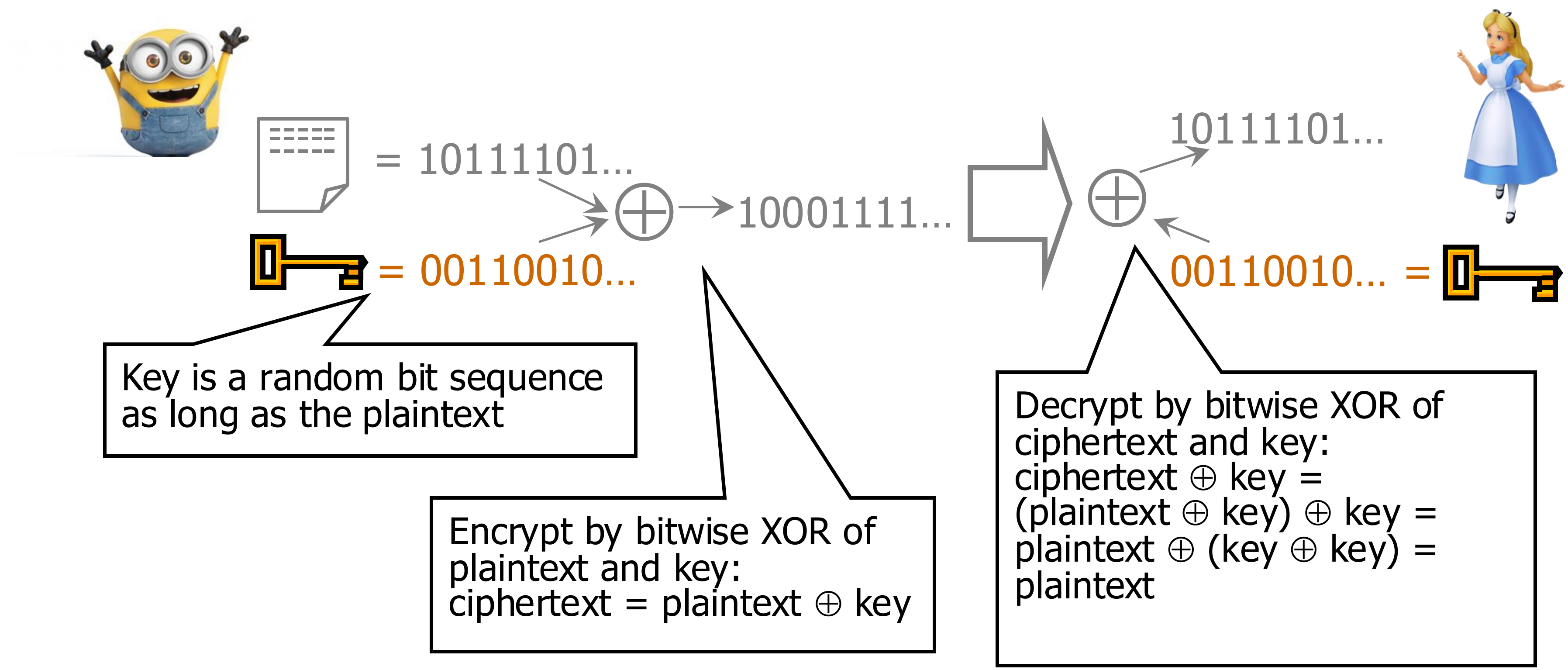
One-Time Pad (Vernam Cipher)



Cipher achieves perfect secrecy if and only if there are as many possible keys as possible plaintexts, and every key is equally likely *(Claude Shannon, 1949)*

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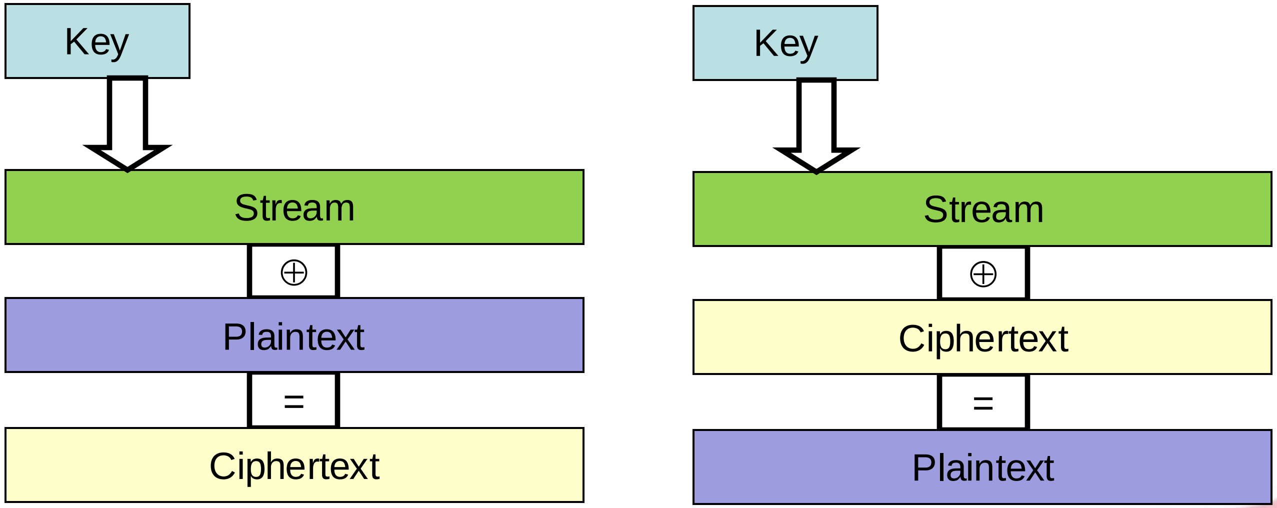
Stream Ciphers

- Start with a secret key ("seed")
- Generate a keying stream
  - Uses a Pseudo-Random Number Generator (PRNG)
- Combine the stream with the plaintext to produce the ciphertext (typically by XOR)



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Pseudo Random Number Generator

- Commonly constructed using Linear Feedback Shift Registers (LFSRs)
- An adversary cannot distinguish a PRNG output from a random sequence

- Example Randomness Tests
  - Monobit tests (frequency of 0s and 1s)
  - Run tests (frequency of runs of different lengths)
- *Pi: A naturally occurring random number*

String 1: 0101010101010101010101010101010101010101010101010101010101010101
String 2: 1100100001100001110111101110110011111010010000100101011110010110

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How to Authenticate Messages?

- content is authentic – bits are as sent
- sequence of messages is proper

Note: Separate problems

- confidentiality that the message is encrypted
- authenticity that the sender is genuine

Authenticating messages - Types

- Authenticator - a value that authenticates a message content
- Message Authentication Code, MAC (cryptographic checksum)
  - public function, with a given secret key produces fixed length value
- Hash or Message Digest
  - public function, which maps message (any length) to fixed-length hash value – no key

Message Authentication Code (MAC)

- Objective: assure authentic content
  - Message is not encrypted
- MAC is small fixed-size data block, appended to message M
- Generator and Validator share secret key

$$MAC_K[M] = F(M, key)$$

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Why use MAC, given encryption?

- Message may not need to be secret, but must be authentic
- Broadcast - only have one site responsible for monitoring authenticity. Broadcast plaintext plus MAC
- Overload - send plaintext messages (i.e. receiver need not decrypt). Authenticate selectively

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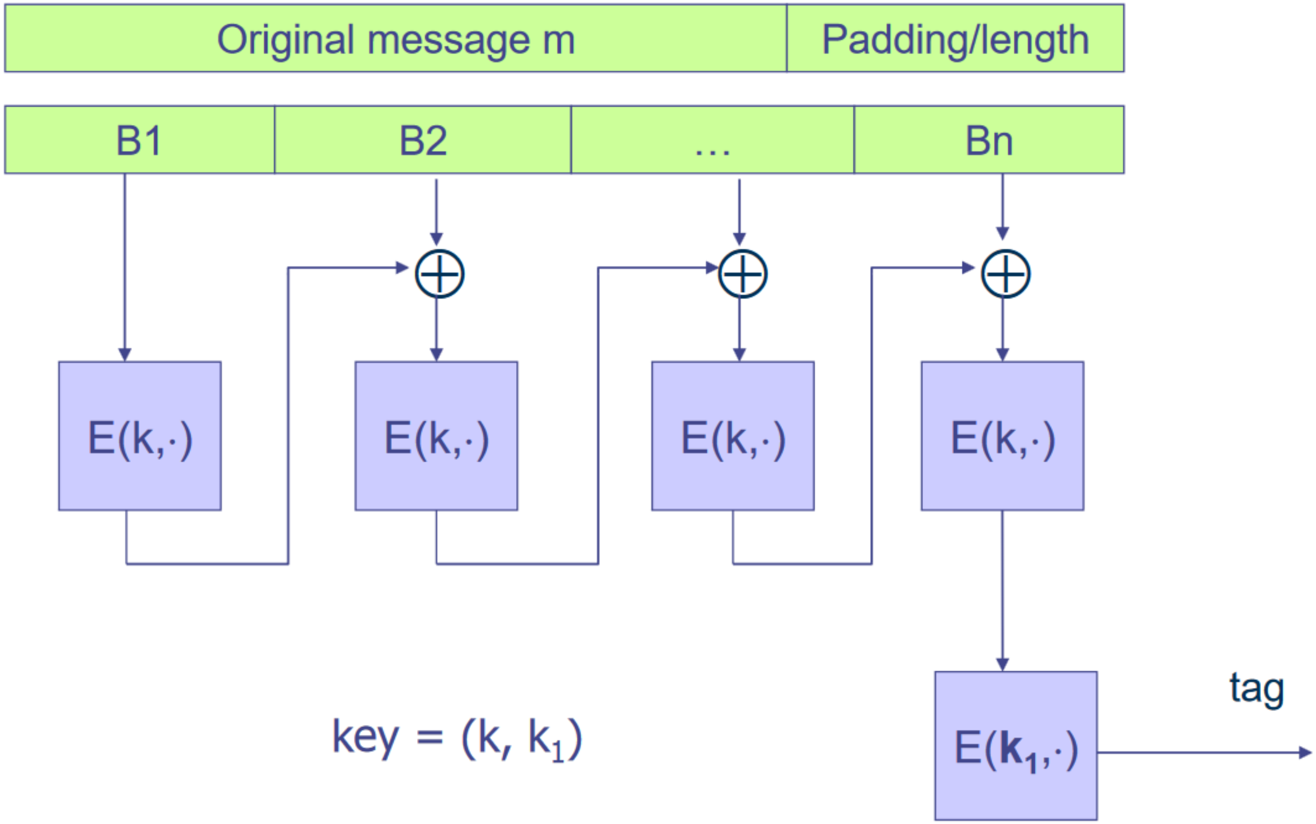
MAC Construction using Encryption



Cipher Block Chaining Message Authentication Code (CBC-MAC)

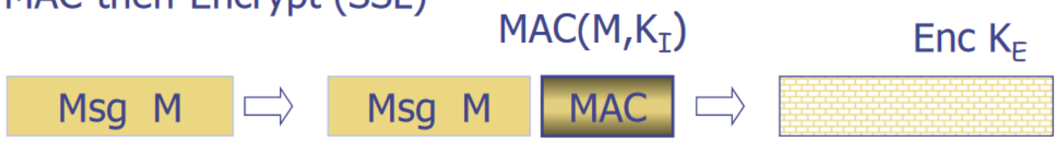
MAC usage

- message authentication (no confidentiality)
  - $A \rightarrow B$: $[M, MAC_K [M]]$
- authentication and confidentiality
  - $A \rightarrow B$: $E_{K1}[M, MAC_K [M]]$
- authentication and confidentiality
  - $A \rightarrow B$: $[E_{K1}[M], MAC_K [E_{K1}[M]]]$

MAC Usage *(contd.)*

Encryption key K_E MAC key = K_I

Option 1: MAC-then-Encrypt (SSL)



Option 2: Encrypt-then-MAC (IPsec)

Option 3: Encrypt-and-MAC (SSH)

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Hash function (Message Digest)

- no key
- like MAC, small amount of data; hash of message gives fixed-size value
- define hash function so that change of any one bit of message will result in different hash value
- hash function is not secret
- one-way; receiver re-computes hash function

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Simple Message Digest: Parity

- parity, or longitudinal redundancy check
- process one bit at a time
- use XOR

$$C = b_1 \oplus b_2 \oplus \cdots \oplus b_{n-1} \oplus b_n$$

- input – arbitrary length message
- size of processed block – one bit
- output – one bit

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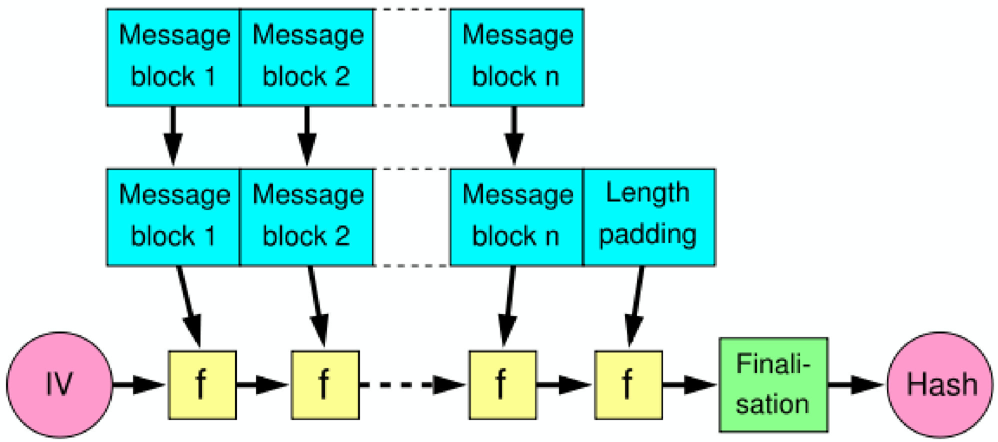
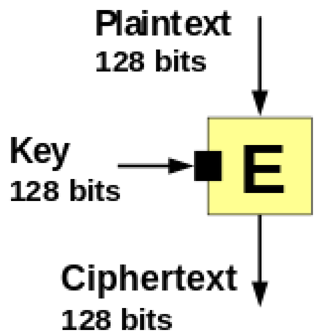
Merkle–Damgård Construction for Hash Functions

- Message is divided into fixed-size blocks and padded
- Use a one-way function f, which takes a chaining variable (of size of hash output) and a message block, and outputs the next chaining variable
- Final chaining variable is the hash value





f built out of block cipher

$$M = m_1 m_2 \ldots m_n;\ C_0 = IV, C_{i+1} = f(C_i, m_i);\ H(M) = C_n$$

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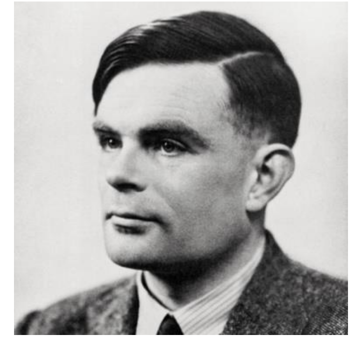
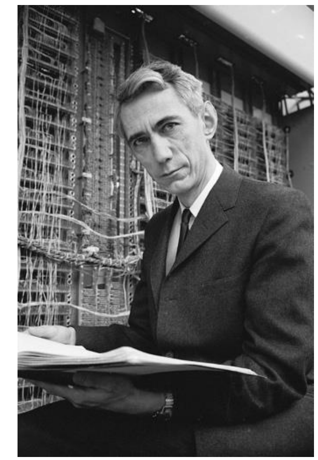
What did we learn?

- **What is Security?**



  - Confidentiality, Integrity, Availability
  - *Authenticity, Privacy, Non-repudiation*



- **What are the building blocks of security?**
  - *Upcoming Lectures*
  - Private-Key Cryptography, Hash, MAC
  - Public-Key Cryptography, Digital Signature

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Further Reading

- Security Engineering
  – by Ross Anderson, available online - http://www.cl.cam.ac.uk/~rja14/book.html

- Handbook of Cryptography
  – by Alfred J. Menezes, Paul C. van Oorschot and Scott A. Vanstone, available online - http://cacr.uwaterloo.ca/hac/

- Applied Cryptography
  – by Dan Boneh and Victor Shoup, available online - http://toc.cryptobook.us/

- Leisure Reading - Simon Singh: *The Code Book*, Fourth Estate 1999

The End