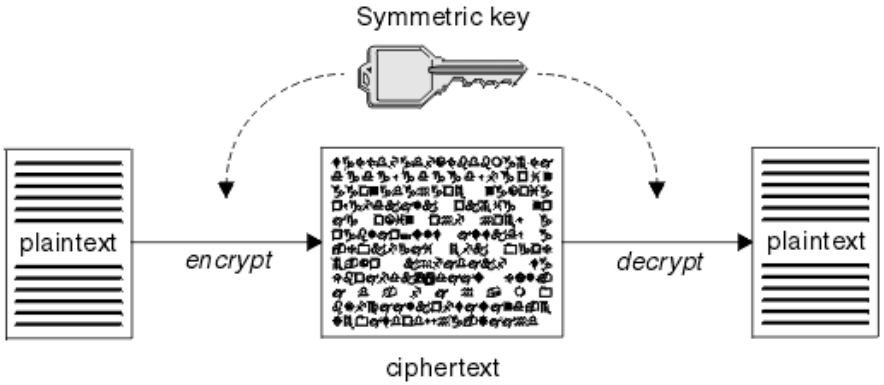

Computer Security

Symmetric Encryption

If you reveal your secrets to the wind, you should not blame the wind for revealing them to the trees.
—Kahlil Gibran

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Random Numbers

- Many uses of *random numbers* in cryptography
  - nonces in authentication protocols to prevent replay
  - session keys
  - public key generation
  - keystream for stream ciphers

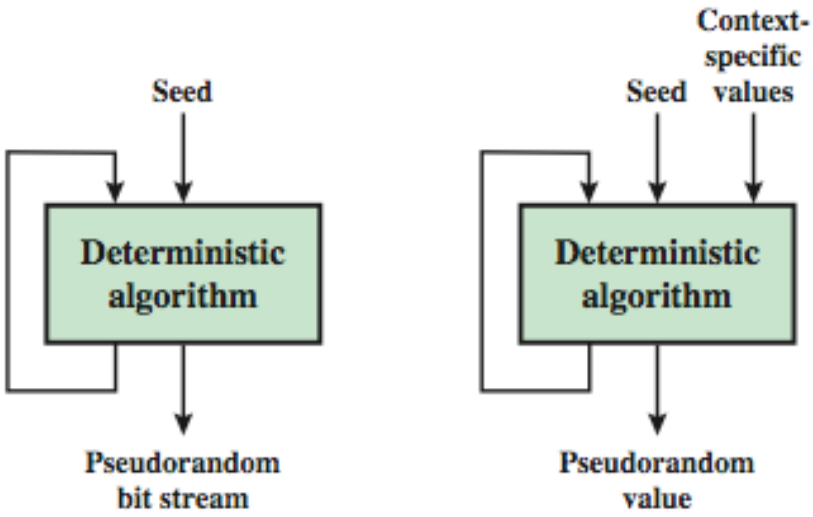
```
89206032161353150760
42991627100678658139
21768097580266432813
57585533115160214822
56368006290497803786
```

- Characteristics of random numbers
  - Statistical randomness
    - Uniform distribution of zeros and ones
    - İndependence of the bits in the sequence
  - Unpredictability of future values from previous values
- True random numbers provide these but very hard to obtain and use in practice

Pseudorandom Number Generators (PRNGs)

- often use deterministic algorithmic techniques to create "random numbers"
  - although are not truly random
  - can pass many tests of "randomness"
- known as "pseudorandom numbers"
- created by "Pseudorandom Number Generators (PRNGs)"

Pseudorandom Number Generators & Psuedorandom Functions



(b) PRNG (c) PRF

- Not much different
  - PRNG output is open-ended while PRF generates fixed size output
  - PRNG is mostly context independent while PRF is context dependent
  - Both may use feedback (there are some non-feedback ones too)
- When used in a cryptographic operation, seed must be kept secret

PRNG/PRF Requirements

- Randomness
  - Uniformity: the occurrence of zeros and ones must be equally likely
  - Scalability: any subseqeunce must pass randomness tests as well
  - Consistency: must not dependent on a particular seed value
- Unpredictability
  - forward unpredictability (next bits cannot be learned using previous bits)
  - backward unpredictability (seed cannot be learned using PRN sequence)
- There are some standard tests (total 15 of them) to check randomness and unpredictability (NIST SP800-22)
- Characteristics of the seed
  - secure
  - if known adversary can determine output
  - so must be random or pseudorandom number (there are some other standard tests for seed randomness as well)

Linear Congruential Generator

- Common iterative technique using:

  $X_{n+1} = (aX_n + c) \bmod m$

  X_0 is the seed
- Given suitable values of parameters can produce a long random-like sequence
- Suitable criteria to have are:
  - function generates a full-period (all values between 0 and m-1)
  - generated sequence should appear random
- Note that an attacker can reconstruct sequence given a small number of values
  - So, not a secure mechanism

Using Block Ciphers as PRNGs

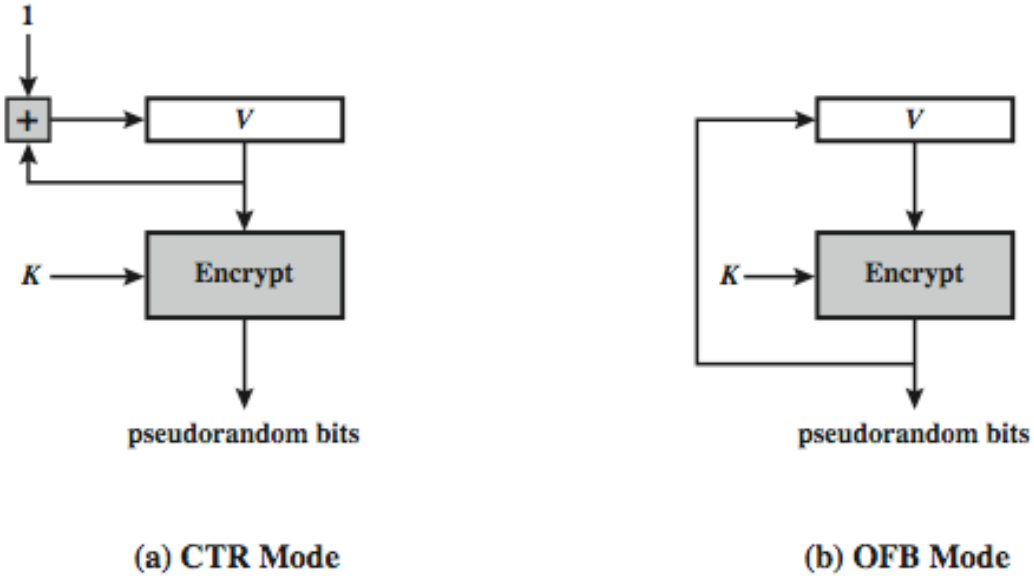
- for cryptographic applications, can use a block cipher to generate random numbers
- often for creating session keys from master key
- Standard methods
- CTR

$$X_i = E_K[V+i]$$

- OFB

$$X_i = E_K[X_{i-1}]$$

$$X_0 = E_K[V]$$

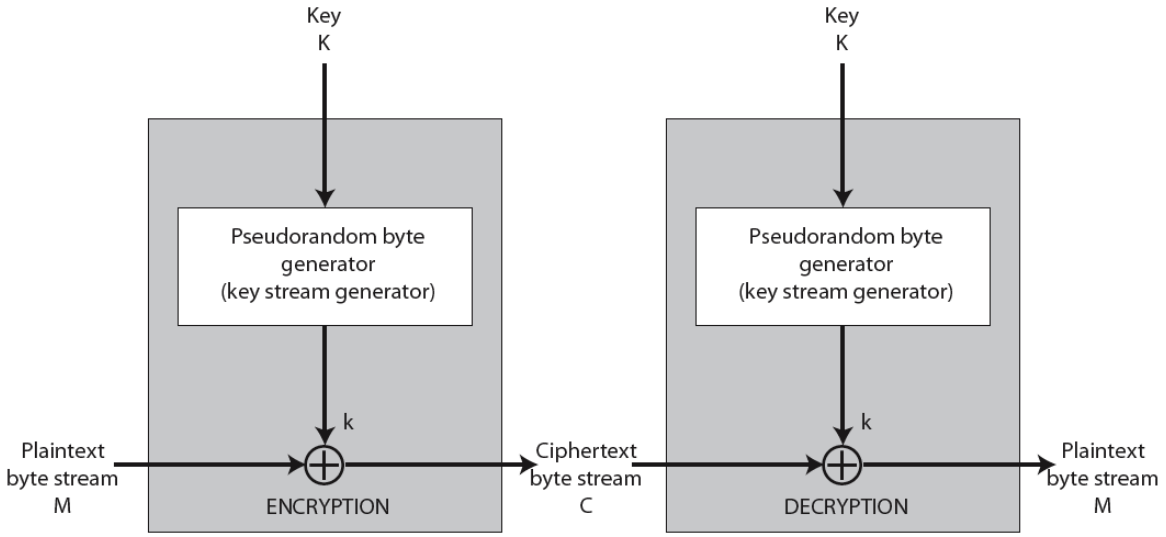


(a) CTR Mode (b) OFB Mode

(V, K) pair is the seed

Stream Ciphers

- process the message bit by bit
- Simply stating
  - a key and a Pseudo Random Number Generator (PRNG) is used to create a (pseudo) random key stream
  - keystream and the plaintext bitwise XORed to create the ciphertext
  - ciphertext is XORed with the same keystream to restore the plaintext



Some Stream Cipher Design Considerations

- A PRNG should eventually repeat
  - long period makes cryptanalysis difficult
- statistically randomness
  - e.g. approx. equal number of 0's and 1's
- large enough key (128-bit would be good to guard against brute-force attacks)

Stream Ciphers

- randomness of keystream destroys any statistical properties in the message
  - as in Vernam cipher and one-time pads
- Better than block ciphers in terms of
  - code space (implementations are simple)
  - throughput (faster per bit en/decryption)
- but must never use the same keystream more than once
  - otherwise the cryptanalyst can XOR two ciphertext streams and find out XOR of two plaintext streams
    - not so difficult to crack

Stream Ciphers

- are useful if data are transferred as a stream
  - web browser
  - voice
  - video
- actually any block cipher can be used as a stream cipher
  - CFB mode of operation (and OFB and CTR)

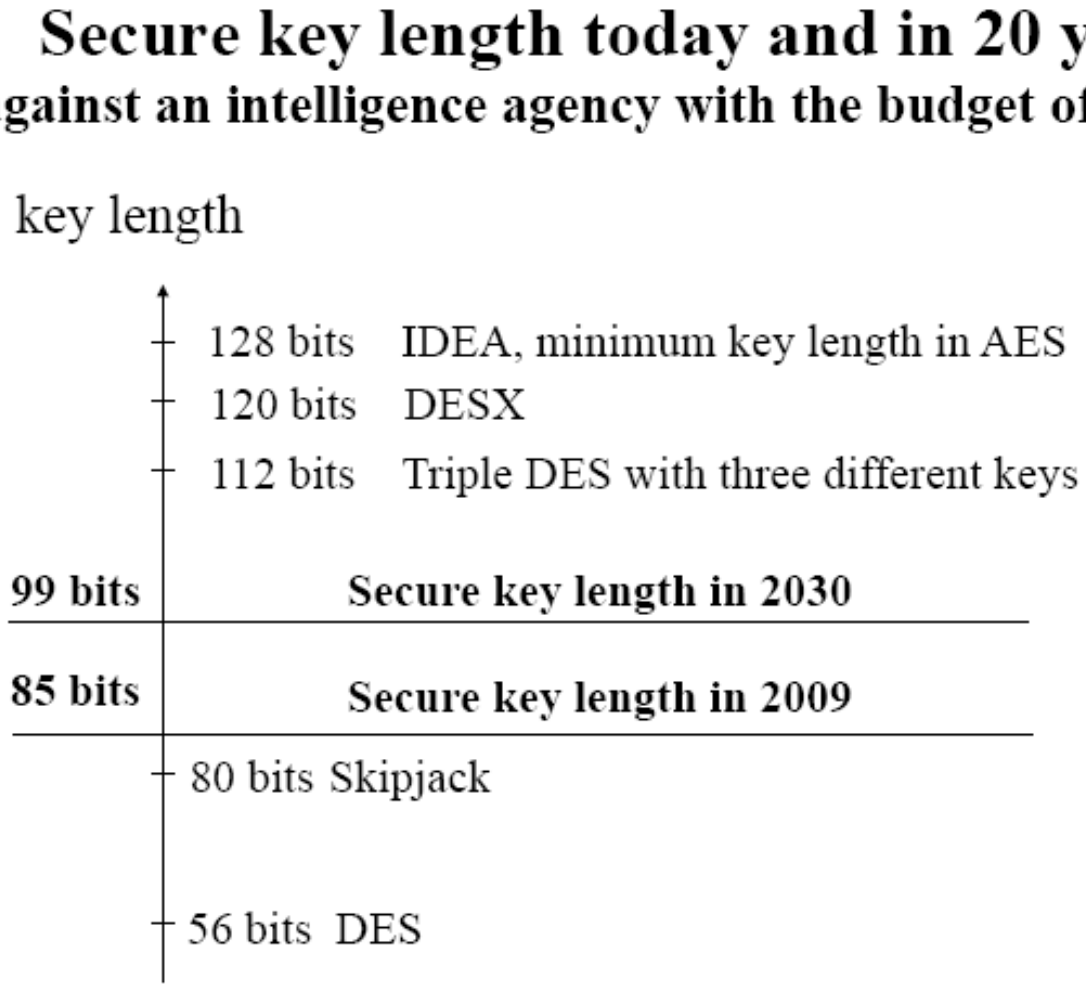
RC4

- Ron's Code 4
- Yet another cipher designed by Ron Rivest
  - owned by RSA Inc.
  - was kept as a trade secret, but in 1994 anonymously posted on the Internet
- variable key size, byte-oriented stream cipher
- simple but effective
  - 8 to 16 machine operations per output byte
- widely used (SSL/TLS, WEP/WPA)
- Some attacks reported, but not practical for key size greater than 128-bit
- However, WEP has a problem due to RC4 key generation
  - not a problem of RC4 in particular

and other symmetric ciphers

- CAST
- Skipjack
- Serpent
- Twofish
- RC6
- Mars
- SAFER+

Discussion



Courtesy of Kris Gaj

Discussion

- Assuming ~92-bit is secure enough for today and Moore's Law continues
  - 1 bit per 18 months to be added
    - 2020's: 93-bit (approx.)
    - 2040's: 107-bit (approx.)
  - with 128-bit, AES we will be secure for a long time
- unless a new efficient cryptanalysis method is found
  - known cryptanalysis methods are not practical for secure key sizes for 3DES, AES, IDEA, etc. (except DES of course)