Modern Symmetric Cryptography

Modern ciphers: types

- Concerning operation
  - Block ciphers (mono-alphabetic)
  - Stream ciphers (poli-alphabetic)
- Concerning their key
  - Symmetric ciphers (secret key or shared key ciphers)
  - Asymmetric ciphers (or public key ciphers)
- Arrangements

	Block ciphers	Stream ciphers
Symmetric ciphers		
Asymmetric ciphers		

Symmetric ciphers

- Secret key
  - Shared by 2 or more peers
- Allow
  - Confidentiality among the key holders
  - Limited authentication of messages
    - When block ciphers are used
- Advantages
  - Performance (usually very efficient)
- Disadvantages
  - N interacting peers, pairwise secrecy ⇒ N x (N-1)/2 keys
- Problems
  - Key distribution

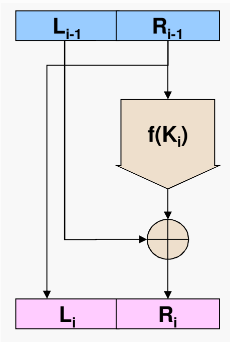
Symmetric block ciphers

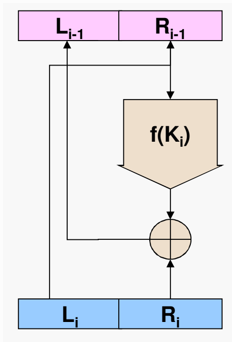
- Usual approaches
  - Large bit blocks for input, output and key
    - 64, 128, 256, etc.
  - Diffusion & confusion
    - Permutation, substitution, expansion, compression
    - Feistel networks, substitution-permutation networks
    - Iterations
    - Sub-keys (key schedules, round keys, etc.)
- Most common algorithms
  - DES (Data Enc. Stand.), D=64 K=56
  - IDEA (Int. Data Enc. Alg.), D=64 K=128
  - AES (Adv. Enc. Stand., aka Rijndael) D=128 K=128, 192, 256
  - Other (Blowfish, CAST, RC5, etc.)

Feistel networks

$L_i = R_{i-1}$
$R_i = L_{i-1} \oplus f(R_{i-1}, K_i)$

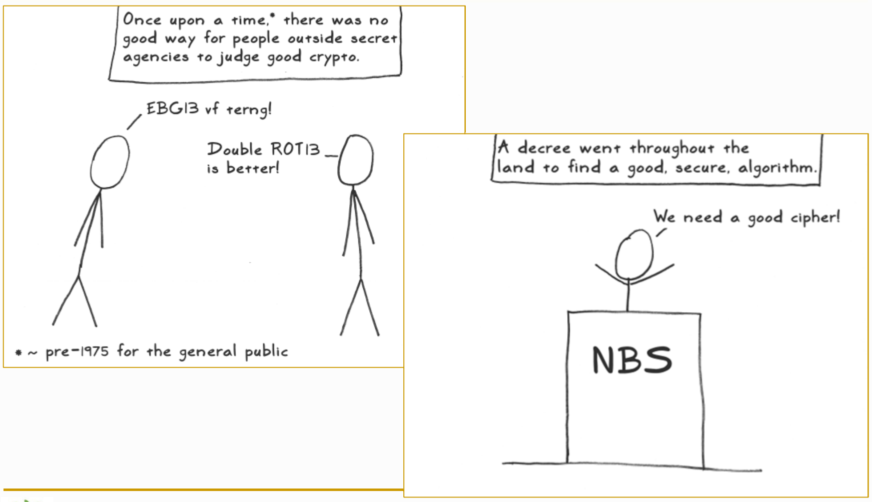
$R_{i-1} = L_i$
$L_{i-1} = R_i \oplus f(L_i, K_i)$





We need a good cipher!

http://www.moserware.com/2009/09/stick-figure-guide-to-advanced.html



DES (Data Encryption Standard)

- 1970: the need of a standard cipher for civilians was identified
- 1972: NBS opens a contest for a new cipher, requiring:
  - The cryptographic algorithm must be secure to a high degree
  - Algorithm details described in an easy-to-understand language
  - The details of the algorithm must be publicly available
    - So that anyone could implement it in software or hardware
  - The security of the algorithm must depend on the key
    - Not on keeping the method itself (or part of it) secret
  - The method must be adaptable for use in many applications
  - Hardware implementations of the algorithm must be practical
    - i.e. not prohibitively expensive or extremely slow
  - The method must be efficient
  - Test and validation under real-life conditions
  - The algorithm should be exportable

Lucipher and DES

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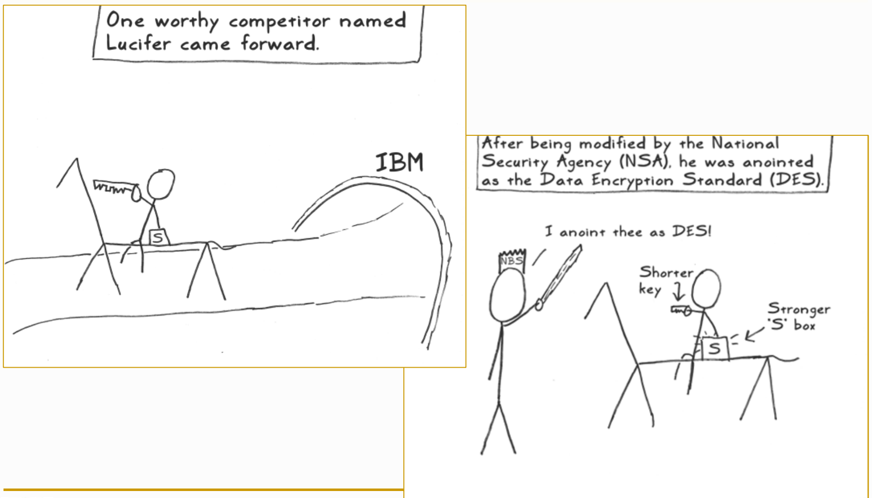
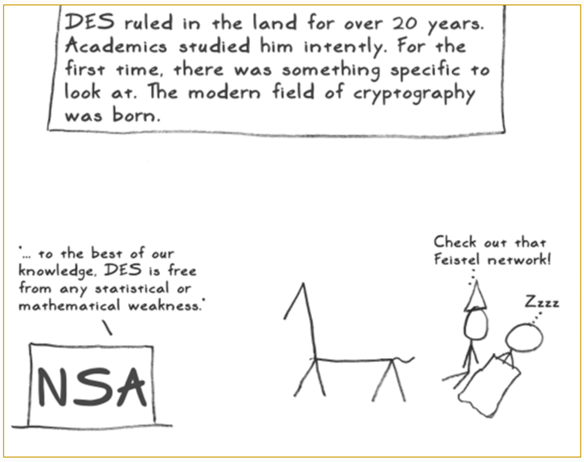


DES: proposal and adoption

- 1974: new contest
  - Proposal based on Lucifer from IBM
  - 64-bit blocks
  - 56-bit keys
    - 48-bit subkeys (key schedules)
  - Diffusion & confusion
    - Feistel networks
    - Permutations, substitutions, expansions, compressions
    - 16 iterations
  - Several modes of operation
    - **ECB** (Electronic Code Book), **CBC** (Cypher Block Chaining)
    - **OFB** (Output Feedback), **CFB** (Cypher Feedback)
- 1976: adopted at US as a federal standard

DES as a milestone



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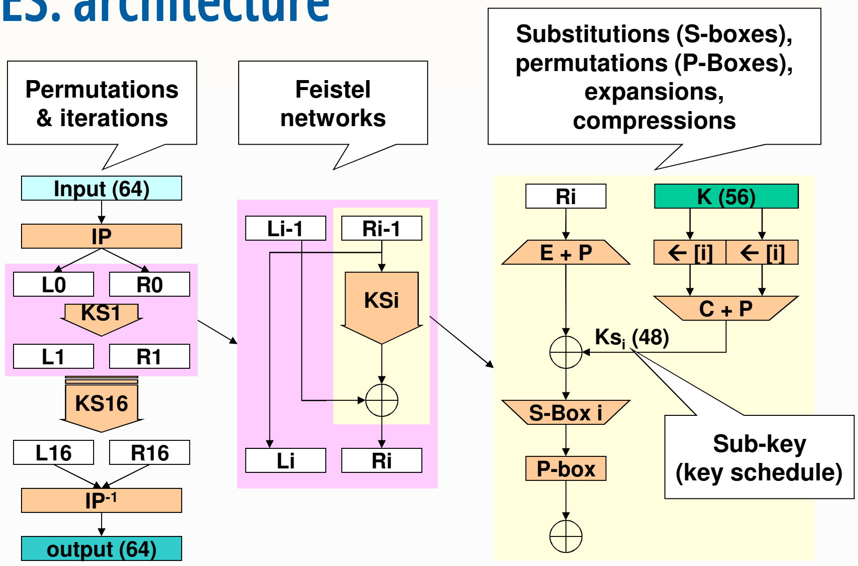
DES: architecture



DES security

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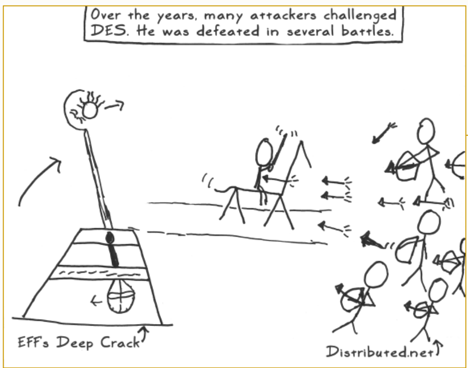

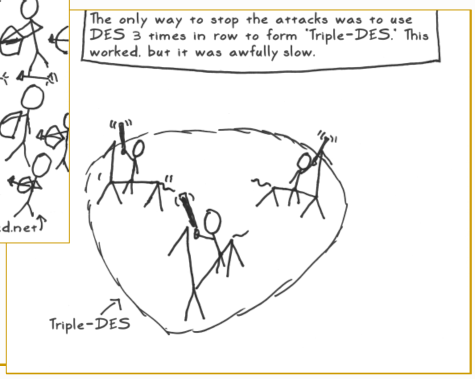

DES: offered security

- Key selection
  - Most 56-bit values are suitable
  - 4 weak, 12 semi-weak keys, 48 possibly weak keys
    - Equal key schedules (1, 2 or 4)
    - Easy to spot and avoid
- Known attacks
  - Exhaustive key space search
- Key length
  - 56 bits are actually too few
  - Exhaustive search is technically possible and economically interesting
- Multiple encryption
  - Double encryption
    - Theoretically not more secure
  - Triple DES (3DES)
    - With 2 or 3 keys
    - Equivalent key length of 112 or 168 bits
    - Secure but ...slow!
  - DES-X
    - $K_1 \oplus DES(K_2) \oplus K_3$
    - Total key length = 64 + 56 + 64 = 184 bits

Replacement of DES (and DES variants)

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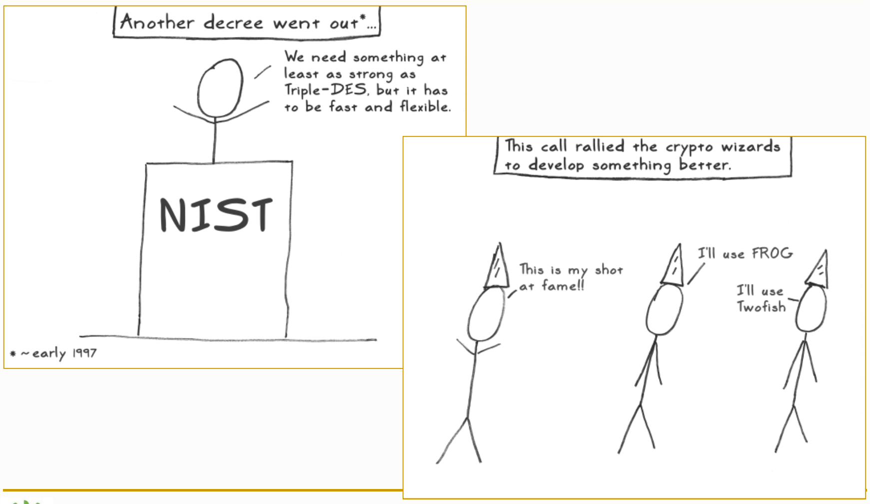
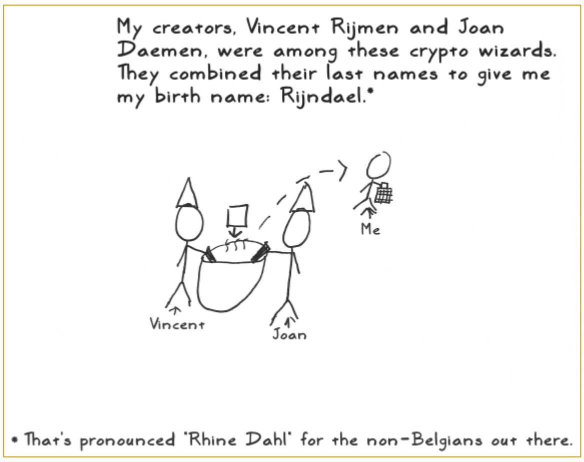


AES (Advanced Encryption Standard)

- 2/Jan/1997: Call for evaluation criteria
  - NIST publicly asked interested parties to propose a criteria to choose a DES successor
  - Many submissions received during 3 months
- 12/Sep/1997: Call for new algorithms
  - Block ciphers
  - 128-bit blocks
  - 128, 192, and 256-bit keys
  - Such ciphers were rare at the time of the call

Rijndael



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AES: evaluation rounds

- ▷ 1st round
  - 15 candidate algorithms were evaluated by the community
  - Conferences were organized for the evaluation
  - Cryptographic weakness were found
  - Performance issues were identified
    - In a variety of hardware
    - PCs, smart cards, hardware implementations
  - Constrained environment were evaluated
    - Limited memory smart cards, low gate count circuits, FPGAs
- ▷ Aug/1999: AES finalists announced
  - MARS, RC6, Rijndael, Serpent, and Twofish

Rijndael selection as AES

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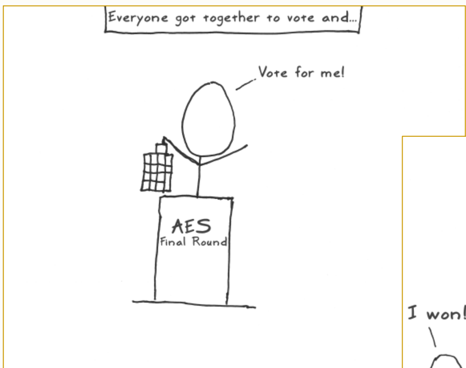
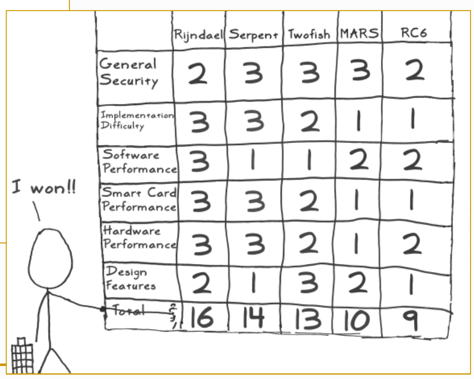
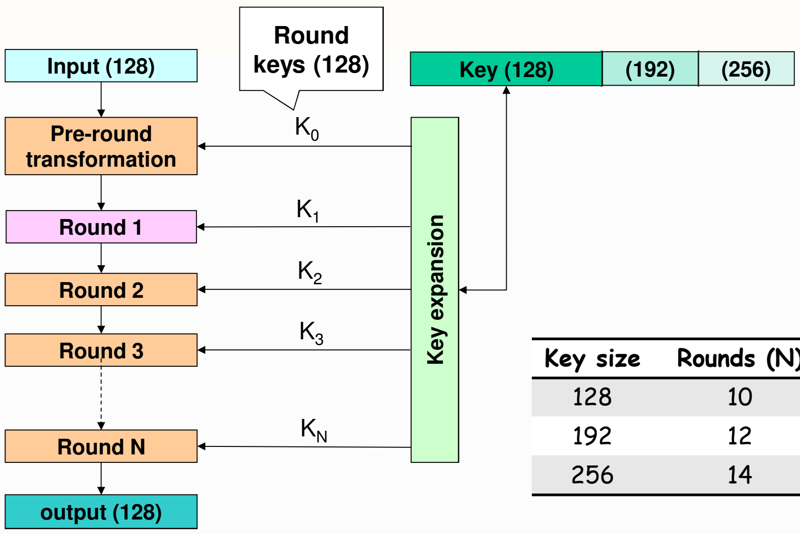




AES: evaluation rounds

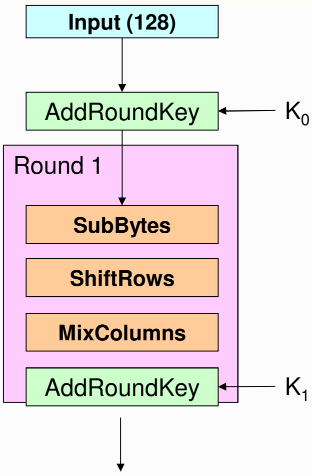
- 2nd round
  - The 5 finalists continued to be evaluated
  - In a final conference the proposal of each algorithm presented their advantage against the other
- 2/Oct/2000: AES algorithm was announced
  - Rijndael was selected
  - Proposed by Vincent Rijmen and Joan Daemen
  - Family of ciphers with different key and block sizes
- 26/Nov/2001: AES was approved by NIST
  - FIPS PUB 197
  - Subset of Rijndael (3 family members)
- Now part of the ISO/IEC 18033-3 standard

AES: architecture

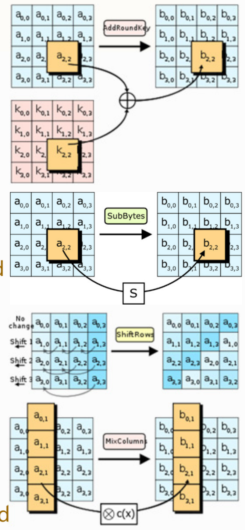


Key size	Rounds (N)
128	10
192	12
256	14

AES: architecture



- AddRoundKey:
  - 128-bit XOR
  - Output is a 4x4 byte matrix
- SubBytes:
  - 256-element S-box
  - Each matrix bytes is substituted
- ShiftRows
  - Rows are rotated left
  - Byte shifts vary (0, 1, 2 & 3)
- MixColumns
  - Each column is transformed
  - Not performed in the last round



https://aescryptography.blogspot.com

AES complexity and speed-up

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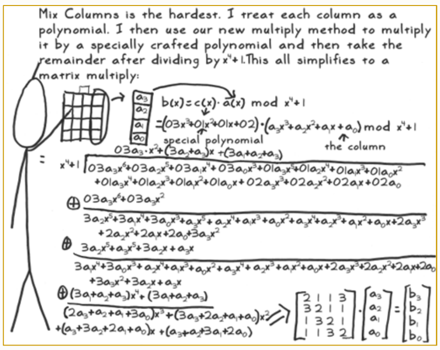
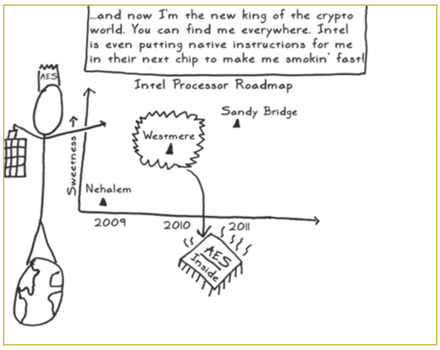




AES in CPU instruction sets

- Intel AES New Instructions (AES-NI)

AESENC	Perform one round of an AES encryption flow
AESENCLAST	Perform the last round of an AES encryption flow
AESDEC	Perform one round of an AES decryption flow
AESDECLAST	Perform the last round of an AES decryption flow
AESKEYGENASSIST	Assist in AES round key generation
AESIMC	Assist in AES Inverse Mix Columns

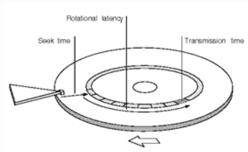
- ARMv8 Cryptographic Extension
- … and other

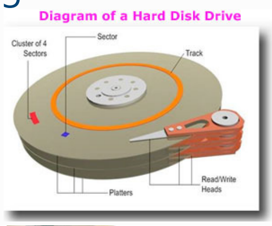
Stream ciphers

- Approaches
  - Cryptographically secure pseudo-random generators (PRNG)
    - Using linear feedback shift registers (LFSR)
    - Using block ciphers
    - Other (families of functions, etc.)
  - Usually not self-synchronized
  - Usually without uniform random access
    - No immediate setup of generator's state for a given plaintext/cryptogram offset
- Most common algorithms
  - A5/1 (US, Europe), A5/2 (GSM)
  - RC4 (802.11 WEP/TKIP, etc.)
  - E0 (Bluetooth BR/EDR)
  - SEAL (w/ uniform random access)

Uniform random access

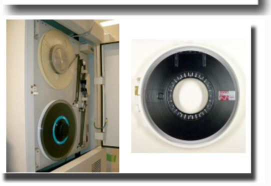
▷ Same time to reach and process any piece of information regardless of its storage location





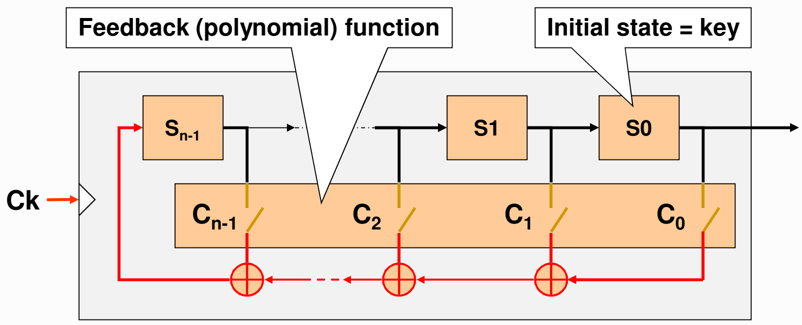
▷ Uniform
- Memory
- Disks (magnetic, optical)
  - Average $T_{access} = T_{seek} + ½\, T_{revolution}$

▷ Non-uniform
- Tapes (audio, video, computer)



http://osr507doc.sco.com/en/PERFORM/disk_IO_mech.html
https://www.ict4u.net/components/backing-storage.php

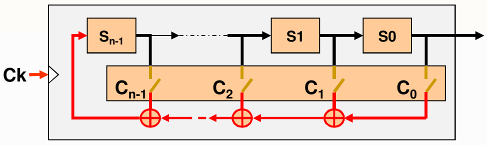
Linear Feedback Shift Register (LFSR)



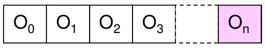
▷ 2^n-1 non-null sequences
- If one of them has a 2^n-1 period length, then all have it

▷ Primitive feedback functions (primitive polynomials)
- All non-null sequences have a 2^n–1 period length

Linear Feedback Shift Register (LFSR)



- Issue
  - If you know N consecutive bits of the output, you know the entire sequence ahead



$O_n = C_0O_0 + C_1O_1 + \ldots + C_{n-1}O_{n-1}$

  - The output must be mixed with something else …

Generators using many LFSR: A5/1 (GSM)