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CRYPTOGRAPHY
From Black Art to Popular Science
PART 2

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Aims of Lecture

- To enjoy ourselves
- To look backwards and forwards

Confidentiality

How do you keep a secret?

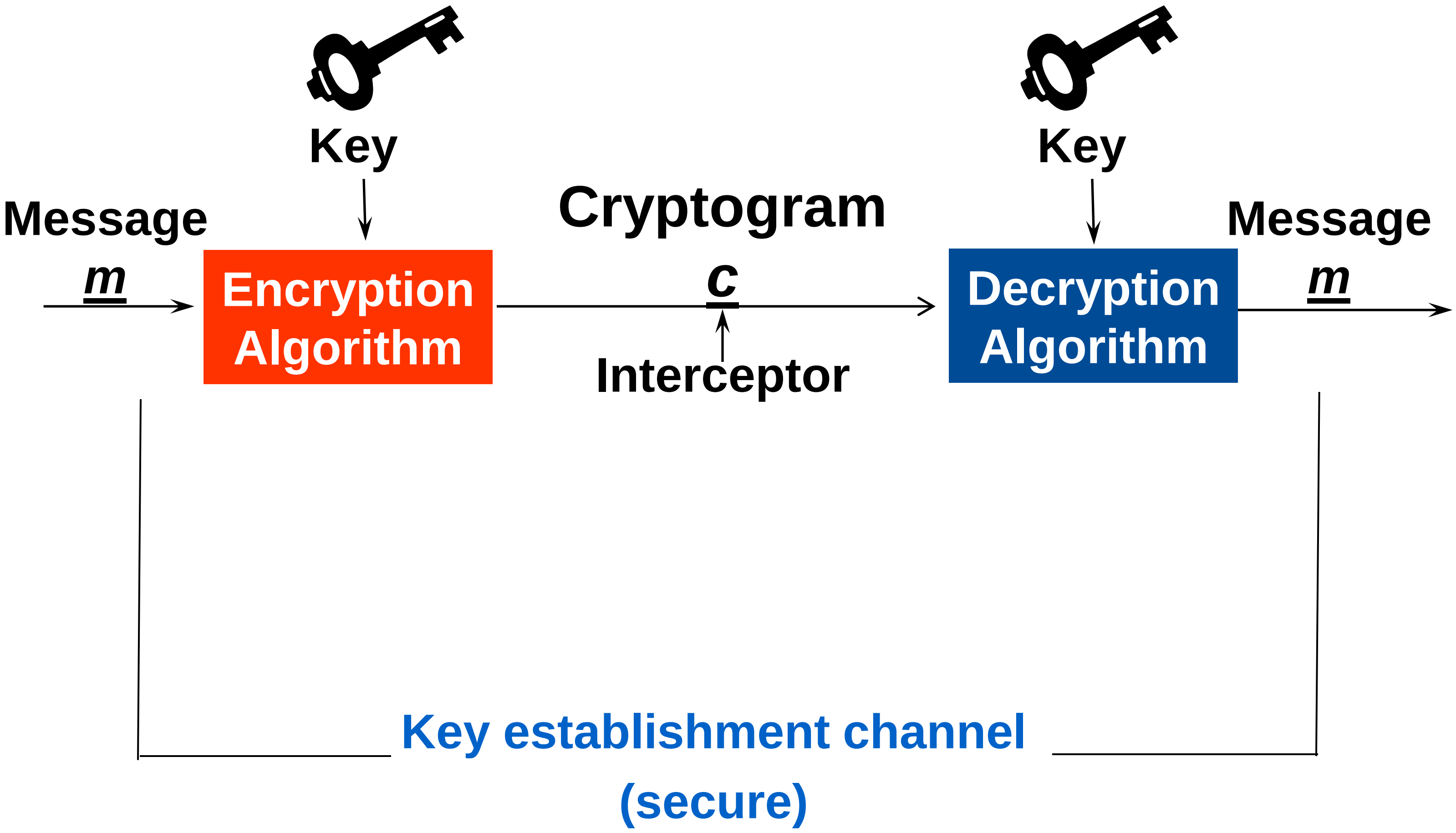
- Don’t let anyone have access to the information
- Disguise it so that ‘unauthorised’ people cannot understand it
  - Shared secrets rely on trust
  - Trust in people, processes, technology

The ‘Secure Channel’ Concept

AIM: To send confidential information over an insecure network

- We achieve this by building a “secure channel” between two end points on the network
- Typically offering:
  - Data origin authentication
  - Data integrity
  - Confidentiality
- Cryptography is an important tool

Early Definition of a Cipher System



Breaking Algorithms

- Being able to determine plaintext from ciphertext without being given key
- Exhaustive key search is always (theoretically) possible

Well Designed (Symmetric) Algorithm

- ‘Easiest’ attack is exhaustive key search

Strong Algorithm

- Well designed with a large number of keys

NOTE: History is full of instances where algorithms were assumed to be well designed but ……

Warning

- If you use strong encryption and lose the decryption key then you have lost the information ‘forever’
- Danger of ‘outsourcing’ or default encryption

A Little History: Ancient Ciphers

Simple Substitution Cipher

There are 403,291,461,126,605,635,584,000,000 keys

NOT well designed

- Frequency analysis attacks

Be Careful!

Question: Is Simple Substitution Cipher broken?

Short answer: Yes

Challenge: If cryptogram is XAV and plaintext is 3 letter English word then what is that word?

Reality: Frequency analysis attacks only work on reasonably long messages(> 200 letters)

Breaking a Cipher

- ‘Broken’ is an emotive term
- Attacks often work only in unrealistic conditions chosen by attacker
- Always understand assumptions associated with the term
- For algorithms:
  - Ciphertext only
  - Known plaintext attack
  - Chosen plaintext attack

Early Polyalphabetic Ciphers

- Encrypt one letter using a Simple Substitution Cipher key and then change key
- Implementation was problem:
  - Difficult to make keys independent of each other
- One Time Pad
- Enigma (rotors and superencipherment)

Superencipherment and Rotation

a b c d e f g h i j k l m n o p q r s t u v w x y z
B I M F N W X A Z H Y L U C T V S K O R G Q P J E D

a b c d e f g h i j k l m n o p q r s t u v w x y z
C D J R S V E L T F K G U Y O Z X W P Q N A B M I H

So a → D   b → T etc

After 1 letter

I M F N W X A Z H Y L U C T V S K O R G Q P J E D B
C D J R S V E L T F K G U Y O Z X W P Q N A B M I H

After 26 letters

B I M F N W X A Z H Y L U C T V S K O R G Q P J E D
D J R S V E L T F K G U Y O Z X W P Q N A B M I H C

Enigma Machine

- Polyalphabetic cipher with large period
- Day key (3 letters in code book)
- Message key (3 'randomly selected' letters protected by day key)
- Problems:
  - Operators determined random selection
  - Message key sent twice
  - A message letter was never represented by itself in the cryptogram

Bletchley Park

Some Important Changes since 1945

- Advent of software
- Advent of fast computers
- Advent of new communications media
- Advent of binary codes
- Increase in general awareness
- Many applications other than provision of confidentiality
- Public key cryptography
- Seen as part of a wider discipline: Information Security

Attitudes to Cryptography

Some comparisons 1976 and 2009

1976: Cryptography was Black Art

2009: Cryptography is popular science

1976 DES: Design details secret

2009 AES: Continuous public scrutiny

1976: Strict (Enforceable) Export Control

2009: Strong algorithms freely available

Cryptographic Implementation

1976: Minimum strength to provide adequate security

2009: Maximum strength that implementation constraints allow

During this period cryptography has become recognised as part of a much wider topic: Information Security

Popular Does Not Mean Easy

- Golf is a popular sport
- Anyone can swing a golf club
- Occasionally a complete novice will hit a good tee shot
- Being a professional is hard work
  - Training
  - Practice

Royal Holloway: Our Most Famous Ex-Student?

Two of the Most Significant Cryptography Publications since 1975

New Directions in Cryptography:

Diffie, W. and Hellman, M.E.

Trans IEEE Inform.Theory. IT-22

644-654, November 1976

Federal Information Processing Standards Publication 46

Announcing the DATA ENCRYPTION STANDARD

January 1977

Kerchoff’s Principle

- The security of a cryptographic system should not depend on keeping the encryption algorithm secret

It does not say

- The encryption algorithm should be made public

However

- Anyone assessing the security of a cryptographic system needs to have confidence that the algorithm is strong

Some Principles

- Security by obscurity is unsafe
- Obscurity can help security

A Never Ending Debate

- What gives us confidence in an algorithm?
  - Standards?
  - Ask the opinions of experts?
- Early debate
  - Publicly known or proprietary algorithms?
  - Less of an issue now than in the 1980s

WARNING

The fact that an algorithm is published and unbroken says nothing about its strength

Recognising Well Designed Algorithms

Some issues

- No proof of security for symmetric algorithms
- What is role of referee if encryption algorithm is submitted for publication?
- Why do academics try to break algorithms? Is it worth it for them?
- Early publications attacked DES, but some other published algorithms were not publicly attacked
- What would have been the consequences if someone had broken DES in the 1980s?

It is NOT just about Algorithms

Early 1980s:

- Thorn EMI conference

  “Security is People”

Early 1990s:

- Ross Anderson’s paper

  “Why crypto systems fail”

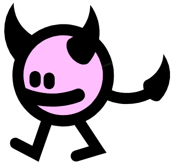
Use of Cryptographic Algorithms

- An algorithm has many uses
- Adaptation by modes of operation
- Protocols to apply the algorithm
- Design of secure protocols
- Key Management supports it

Misuse of Cryptography

Grade

Good student xxxxx



Bad student xxxxx

Grades can be changed

Cryptographic System

- The use of strong algorithms prevents attackers from calculating or guessing keys
- Keys need to be stored and/or distributed throughout the system
- Keys need protection

Protecting Keys (Storage or Distribution)

- Physical security
  - Tamper Resistant Security Module (TRSM)
  - Tokens (Smart Cards)
  - Armed guards
- Components
  - Secret Sharing Scheme
- Key hierarchies
  - Keys encrypted using other keys
  - Lower level keys derived from higher level ones

Side Channel Attacks

To find a cryptographic key

- **Exhaustive key search attacks** try to find the secret key by random trial and error
- **Side channel attacks** try to use additional information drawn from the physical implementation of the cryptographic algorithm at hand so as to be **substantially better than trial and error**

Evolution of Side Channel Attacks

Dec 11, 1995: Paul Kocher announces timing attack on the sci. crypt news group:

"I've just released details of an attack many of you will find interesting since quite a few existing cryptography products and systems are potentially at risk. The general idea of the attack is that secret keys can be found by measuring the amount of time used to process messages. The paper describes attacks against RSA, fixed exponent Diffie-Hellman, and DSS, and the techniques can work with many other systems as well".

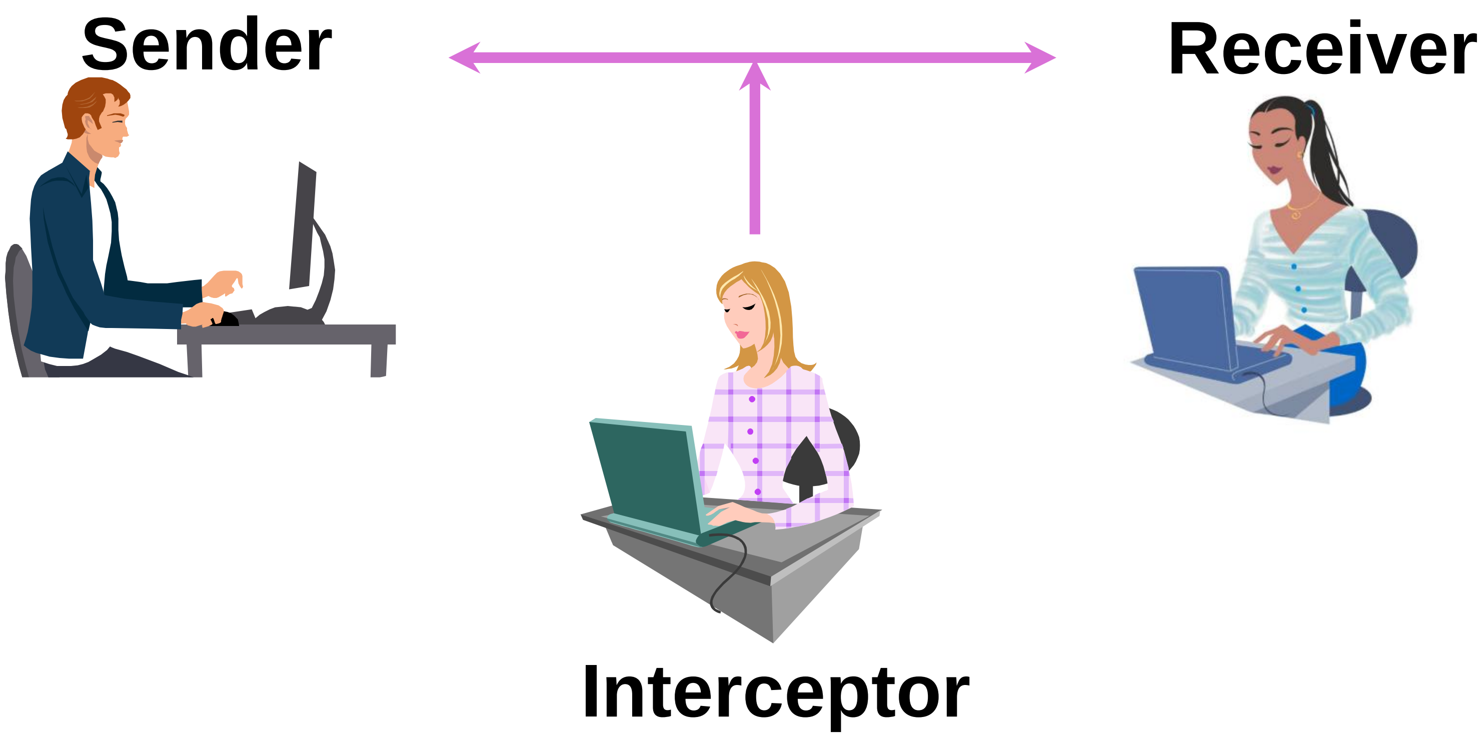
Control of Encryption

The widespread use of encryption for confidentiality has always been a cause of concern for Governments

Over simplification of objectives

- To provide strong encryption for use for ‘good’ purposes
- To be able to break encryption used for ‘bad’ purposes

Saints or Sinners ?



Who are the 'good' guys ?

Governments'/Law Enforcement's Dilemmas

- Do not want to intrude into people's private lives
- Do not want to hinder e-commerce
- Want to have their own secure communications
- Occasionally use interception to obtain information
- Occasionally need to read confiscated, encrypted information

Control of Encryption

Export Control

- Easier in 1970s and 1980s
- The application process has changed
- Black Box Deception no longer possible (trapdoors)

Key Escrow

- Offers secrecy from everyone except Government (in special circumstances)

Regulation

NOTE: If someone wants your key they might

- Break the algorithm
- ‘Find’ the key in the system
- Be given it

Black Box Deception

- Randomness
- Prime generation
- Reduce effective key search

Loss of Control of Encryption

- Academic papers
  - Attacks on DES
  - New algorithms
- Text books
- Need for international systems

Newton Minow, Speech to the Association of American Law Schools, 1985

- After 35 years, I have finished a comprehensive study of European comparative law
- In Germany, under the law, everything is prohibited, except that which is permitted
- In France, under the law, everything is permitted, except that which is prohibited
- In the Soviet Union, under the law, everything is prohibited, including that which is permitted
- And in Italy, under the law, everything is permitted, especially that which is prohibited

The Political Breakthrough

- GSM
- ETSI produced (shared) encryption algorithm for Europe
- Designed to be as secure as the existing ‘land line’ network

Authentication

- It is important to authenticate people and devices
- Man-in-the-Middle Attacks
- How to beat a Grand Master at chess

User Recognition Methods

1. Something known by user (eg PIN, password)
2. Something owned by user (eg smartcard)
3. Biometric property of user

NOTE: At least 2 and often all 3 of these methods are combined

User Authentication Using Symmetric Cryptography

Can only take place between two parties who are prepared to co-operate with each other

Typical scheme:

A and *B* share a secret key *K* which (they believe) is known only to them

If *A* receives a message encrypted with key *K* then *A* believes that the message originated from *B*

Note: *A* and *B* need to protect against replays etc

New Directions in Cryptography: 1975

- Conventional or Symmetric
  - Decryption key easily obtained from encryption key
- Public or Asymmetric
  - Computationally infeasible to determine decryption key from encryption key

NOTE: CESG initially referred to this as non-secret encryption

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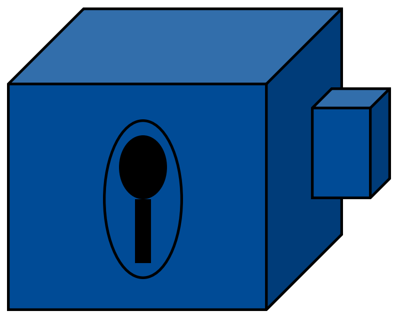

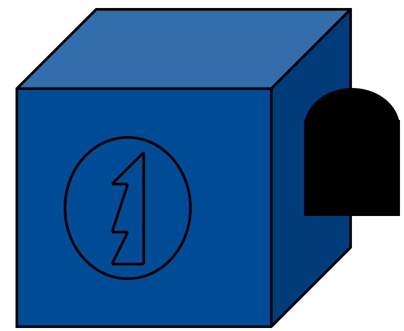

Mortice Lock

If you can lock it, then you can unlock it

Bevelled Sprung Lock

Anyone can lock it, only keyholder can unlock it

Authentication Using Public Key Cryptography

- User is only person who can use private key
- Anyone can use public key to check that a private key was used

Attacks on Public Key System

To impersonate you I may either:

- Obtain your private key
- Get my public key accepted as yours

Defence need **P**ublic **K**ey **I**nfrastructure (PKI)

- Significant overhead
- Trusted third party

A Fact of Life !

- In theory there is no difference between theory and practice. In practice there is.

RSA: The Theory

- The published modulus is the product of 2 secret primes
- Knowledge of the secret primes makes it easy to find the private key
- In general, determining the private key appears to require knowledge of the primes
- Factorisation is difficult
- So, for large moduli, RSA is secure

RSA: In Practice

- Early implementations used prime generation with only a million primes
- Exhaustive prime searches were possible
- The theory was irrelevant!

Is Cryptography built on a ‘sound’ basis?

“Many cryptographic systems rely on the inability of mathematicians to do mathematics”.

(Donald Davies: LMS Lecture)

Tongue in cheek?

Existence proofs do not provide solutions

Algorithms should be implementable

Accuracy of Information

- Information on a database is useless unless it is accurate
- Prevention of alteration
  - Deny access
- Detection of alteration
  - Cryptographic check sum
    - Digital signatures
    - MACs

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Dispute Resolution

- Symmetric systems
  - No (cryptographic) dispute resolution between 2 key holders
  - Protection against 3rd parties only, not each other
- Digital signatures
  - Need asymmetric system
  - PKI overhead?

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Hand-Written Signatures

– Intrinsic to signer
– Same on all documents
– Physically attached to message
– Beware plastic cards.

- Digital Signatures
  – Use of secret parameter
  – Message dependent.

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What is a Binary String?

A bit string of length *s*

1. A string of bits
2. An integer for 0 to $2^s - 1$
3. A sequence of integers
4. Coordinates to a look-up table
5. Vector in $V(s,2)$
6. Binary polynomial (degree at most $s - 1$)
7. Indicator set for integers 0 to $s - 1$
8. Your choice?

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Classification of Techniques

Bit / Block operation

Message dependence/independence

Positional dependence/independence

Error Propagation

If the decryption process has the property that accepting an input with 1-bit in error produces an output with more than 1 unreliable bit, then we say there is ERROR PROPAGATION

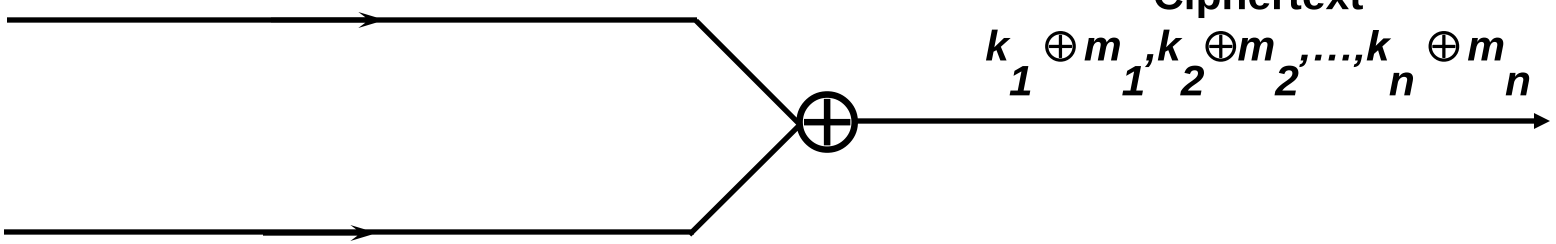
- Block encryption leads to error propagation

Vernam Cipher

Random sequence $k_1, k_2, \ldots, k_n$

Ciphertext

$k_1 \oplus m_1, k_2 \oplus m_2, \ldots, k_n \oplus m_n$



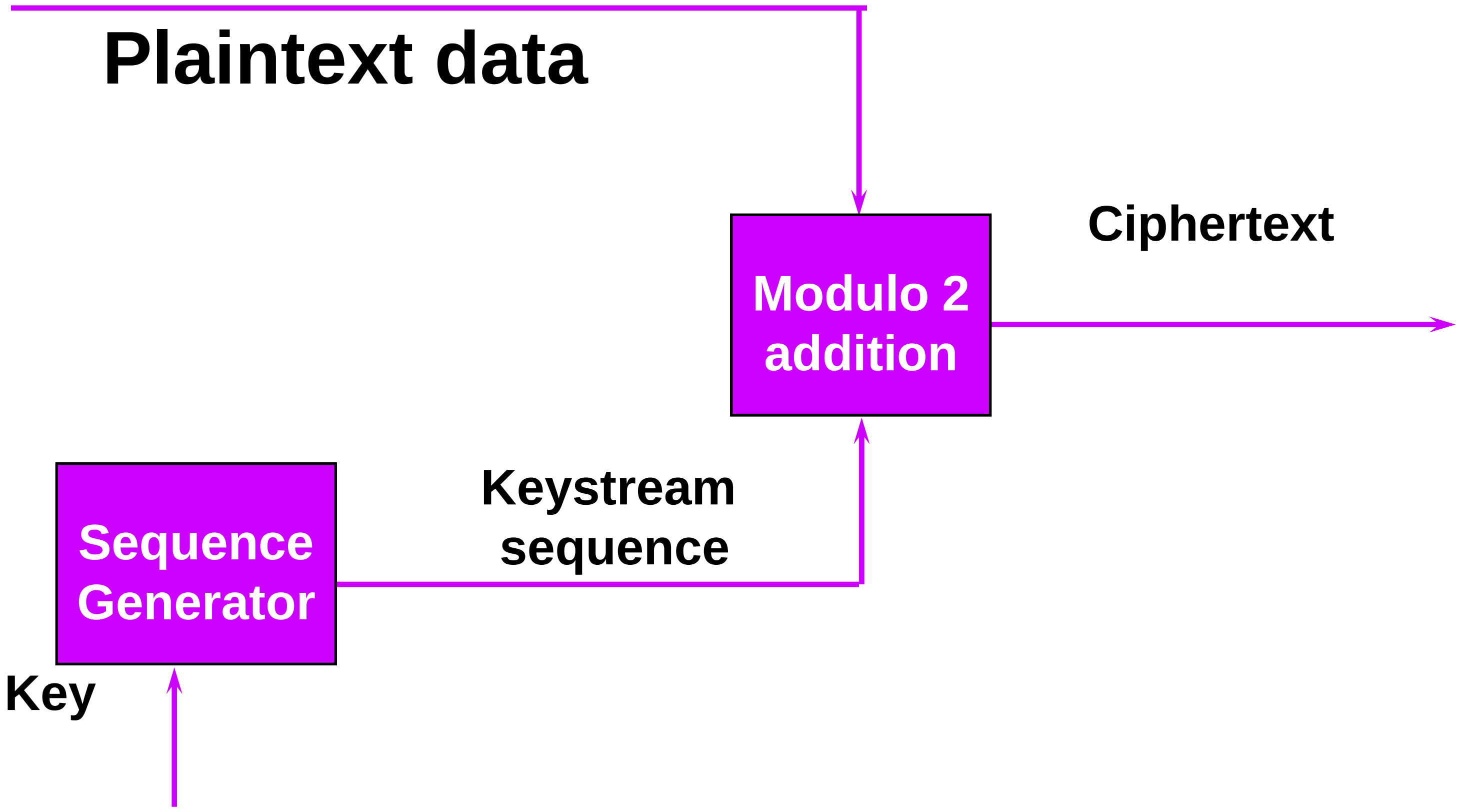
Message $m_1, m_2, \ldots, m_n$

The message and key are bit strings

One-Time Pad

- At least as many keys as messages
- Each key used only once
- Provably unbreakable
- Key management problems
- Requires second communications channel for the key
- Not suitable for most applications

Stream Cipher

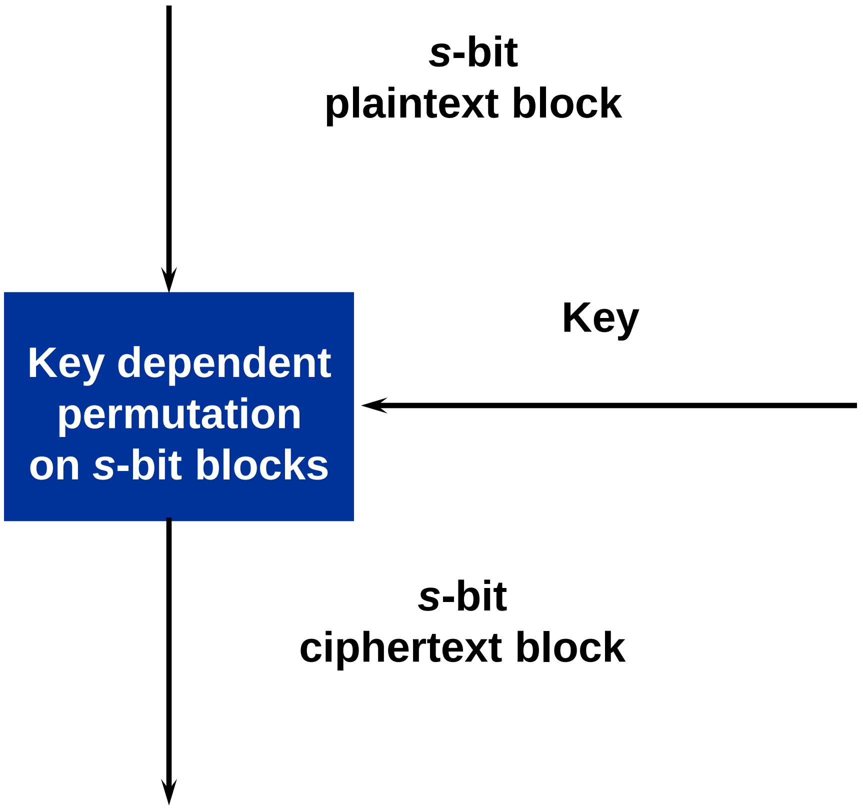


Stream Ciphers

Applications

- Widely used for military and paramilitary applications for both data and digitised speech
- The main reason for their wide use is that military communications are often over poor channels and error propagation is unacceptable

Symmetric Block Cipher System



ECB Mode for a Block Cipher

To encrypt a message *m* using a block cipher with block size *s*

(a) Divide the message into ‘blocks’ of *s*-bits
(b) Use padding (with agreed convention) if needed to ensure that the ‘last’ block has *s* bits
(c) Encrypt each block individually

NOTE: Identical message blocks give identical cryptogram blocks

Fast DES Key Search

DES has 56-bit key

DES Breaker used with Internet search

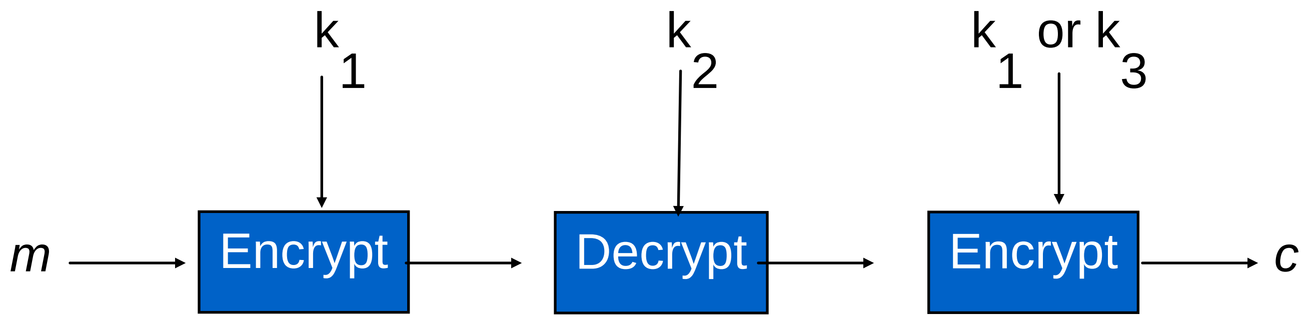
Key found in less than a day

Consequences

The use of single length DES cannot be justified for protecting ‘valuable’ information with a cover time of more than a few minutes

Triple-DES

There are several different proposals for 3DES



Typical deployments use 2-key or 3-key EDE

DES Conclusions

- We believe that DES is a well-designed cipher
- Best attack is exhaustive search – 30 years after design
- Exhaustive search is practical
- Enter AES (2002)

64-bit Key Search

- RC5 secret key challenges
- Key found 26.9.02
- Took about 4 years
- Task undertaken by distributed network
- Used 331,252 volunteers

Future Developments ?

- Steganography
  - You hide information rather than distort it
  - Harder to detect?
- Quantum
  - Quantum key establishment
  - Quantum cryptography
  - Quantum computing
- Provable security
  - Academic ‘dream’ or reality?
- Default encryption
  - Who looks after keys? (liability issues)

European Convention on Human Rights 1950
UK Human Rights Act 1998

A Clear Statement

ARTICLE 8: RIGHT TO RESPECT FOR PRIVATE AND FAMILY LIFE

1. Everyone has the right to respect for his private and family life, his home and his correspondence

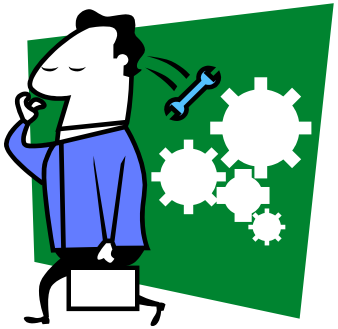
European Convention on Human Rights 1950
UK Human Rights Act 1998

A not so clear caveat

2. There shall be no interference by a public authority with the exercise of this right except such as is in accordance with the law and is necessary in a democratic society in the interests of national security, public safety or the economic well-being of the country, for the prevention of disorder or crime, for the protection of health or morals, or for the protection of the rights and freedom of others

Human Rights Statements

Some problems



- What does the caveat mean?
- Who decides when the exceptions are justified?
- Finding a balance between rights and responsibilities