

CSE331: Introduction to Networks and Security

Lecture 21

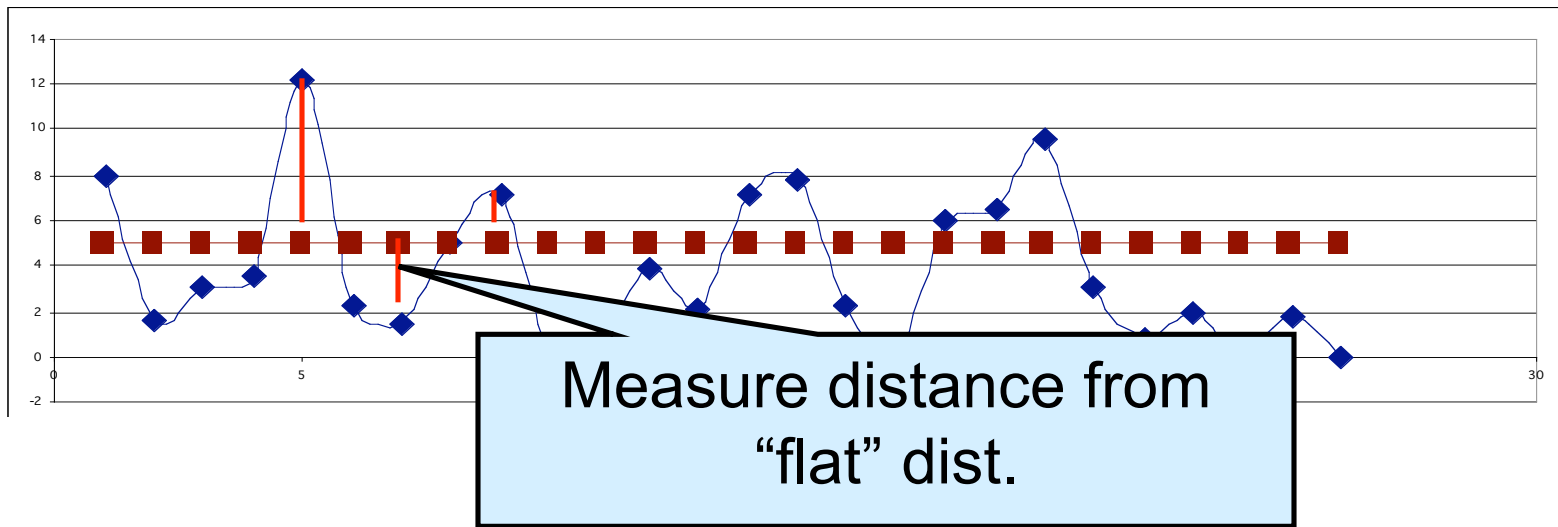
Fall 2006

Announcements

- Homework 2 has been assigned:
 - ****NEW DUE DATE****
 - It's now due on *Friday, November 3rd*.

- Midterm 2 is Friday, November 10th
 - ****NEW DATE****
 - It covers just the material since Midterm 1

Variance: Measure of “roughness”



$$\begin{aligned}\text{Var} &= \sum_{\alpha = a}^{\alpha = z} (\text{prob}(\alpha) - 1/26)^2 \\ &= \dots \\ &= \left(\sum_{\alpha = a}^{\alpha = z} \text{prob}(\alpha)^2 \right) - 1/26\end{aligned}$$

Estimate Variance From Frequency

- $\text{prob}(\alpha)^2$ is probability that any two characters drawn from the text will be α
- Suppose there are n ciphertext letters total
- Suppose $\text{freq}(\alpha)$ is the frequency of α
- What is likelihood of picking α twice at random?
 - $\text{freq}(\alpha)$ ways of picking the first α
 - $(\text{freq}(\alpha) - 1)$ ways of picking the second α
 - But this counts twice because $(\alpha, \beta) = (\beta, \alpha)$
 - So
$$\frac{\text{freq}(\alpha) \times (\text{freq}(\alpha) - 1)}{2}$$

Index of Coincidence

- But there are $\frac{n \times (n-1)}{2}$ pairs of letters
- ...so $\text{prob}(\alpha)^2$ is roughly $\frac{\text{freq}(\alpha) \times (\text{freq}(\alpha) - 1)}{n \times (n-1)}$
- Index of coincidence: approximates variance from frequencies

$$\text{IC} = \sum_{\alpha = a}^z \frac{\text{freq}(\alpha) \times (\text{freq}(\alpha) - 1)}{n \times (n-1)}$$

What's it good for?

- If the distribution is flat, then $IC \approx 0.0384$
- If the distribution is like English, then $IC \approx 0.068$
- Can verify key length:

keylen	1	2	3	4	5	many
IC	0.068	0.052	0.047	0.044	0.044	... 0.038



Summary: Cracking Polyalphabetic

- Use Kasiski method to guess likely key lengths
- Compute the Index of Coincidence to verify key length k
- k -Slices should have similar IC to English
- Note: digram information harder to use for polyalphabetic ciphers...
 - May want to consider “split digrams”
 - Example: if tion is a common sequence $k=2$ then “ $t?o$ ” and “ $i?n$ ” are likely “split digrams”

Perfect Substitution Ciphers

$$\begin{array}{r} p_1 \ p_2 \ p_3 \ \dots \ p_n \\ \oplus \ b_1 \ b_2 \ b_3 \ \dots \ b_n \\ \hline c_1 \ c_2 \ c_3 \ \dots \ c_n \end{array}$$

- Choose a string of random bits the same length as the plaintext, XOR them to obtain the ciphertext.
- Perfect Secrecy
 - Probability that a given message is encoded in the ciphertext is unaltered by knowledge of the ciphertext
 - Proof: Give me any plaintext message and any ciphertext and I can construct a key that will produce the ciphertext from the plaintext.

One-time Pads

- Another name for Perfect Substitution
- Actually used by US agents in Russia
 - Physical pad of paper
 - List of random numbers
 - Pages were torn out and destroyed after use
- Vernam Cipher
 - Used by AT&T
 - Random sequence stored on punch tape
- Not practical for computer security...



Problems with “Perfect” Substitution

- Key is the same length as the plaintext
 - Sender and receiver must agree on the same random sequence
 - Not any easier to transmit key securely than to transmit plaintext securely
- Need to be able to generate many truly random bits
 - Pseudorandom numbers generated by an algorithm aren't good enough for long messages
- Can't reuse the key

Computational Security

- Perfect Ciphers are *unconditionally secure*
 - No amount of computation will help crack the cipher (i.e. the *only* strategy is brute force)
- In practice, strive for *computationally security*
 - Given enough power, the attacker could crack the cipher (example: brute force attack)
 - But, an attacker with only *bounded resources* is extremely unlikely to crack it
 - Example: Assume attacker has only polynomial time, then encryption algorithm that can't be inverted in less than exponential time is secure.



Kinds of Industrial Strength Crypto

- Shared Key Cryptography
- Public Key Cryptography
- Cryptographic Hashes

- All of these aim for computational security
 - Not all methods have been proved to be intractable to crack.

Shared Key Cryptography

- Sender & receiver use the same key
- Key must remain private
- Also called *symmetric* or *secret key* cryptography
- Often are *block-ciphers*
 - Process plaintext data in blocks
- Examples: DES, Triple-DES, Blowfish, Twofish, AES, Rijndael, ...

Shared Key Notation

- Encryption algorithm
 $E : \text{key} \times \text{plain} \rightarrow \text{cipher}$
Notation: $K\{\text{msg}\} = E(K, \text{msg})$
- Decryption algorithm
 $D : \text{key} \times \text{cipher} \rightarrow \text{plain}$
- D inverts E
 $D(K, E(K, \text{msg})) = \text{msg}$
- Use capital “K” for shared (secret) keys
- Sometimes E is the same algorithm as D

Secure Channel: Shared Keys

Alice



K_{AB}

Bart



K_{AB}

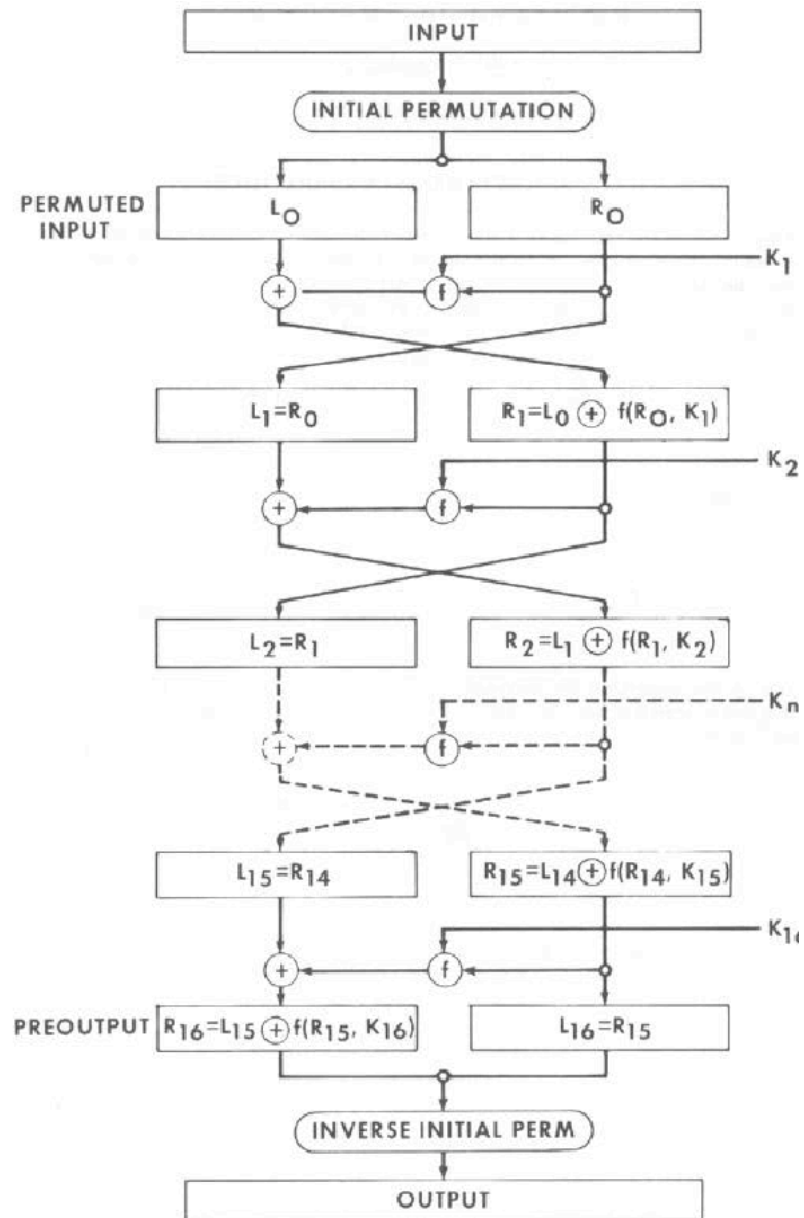
$K_{AB}\{\text{Hello!}\}$

$K_{AB}\{\text{Hi!}\}$

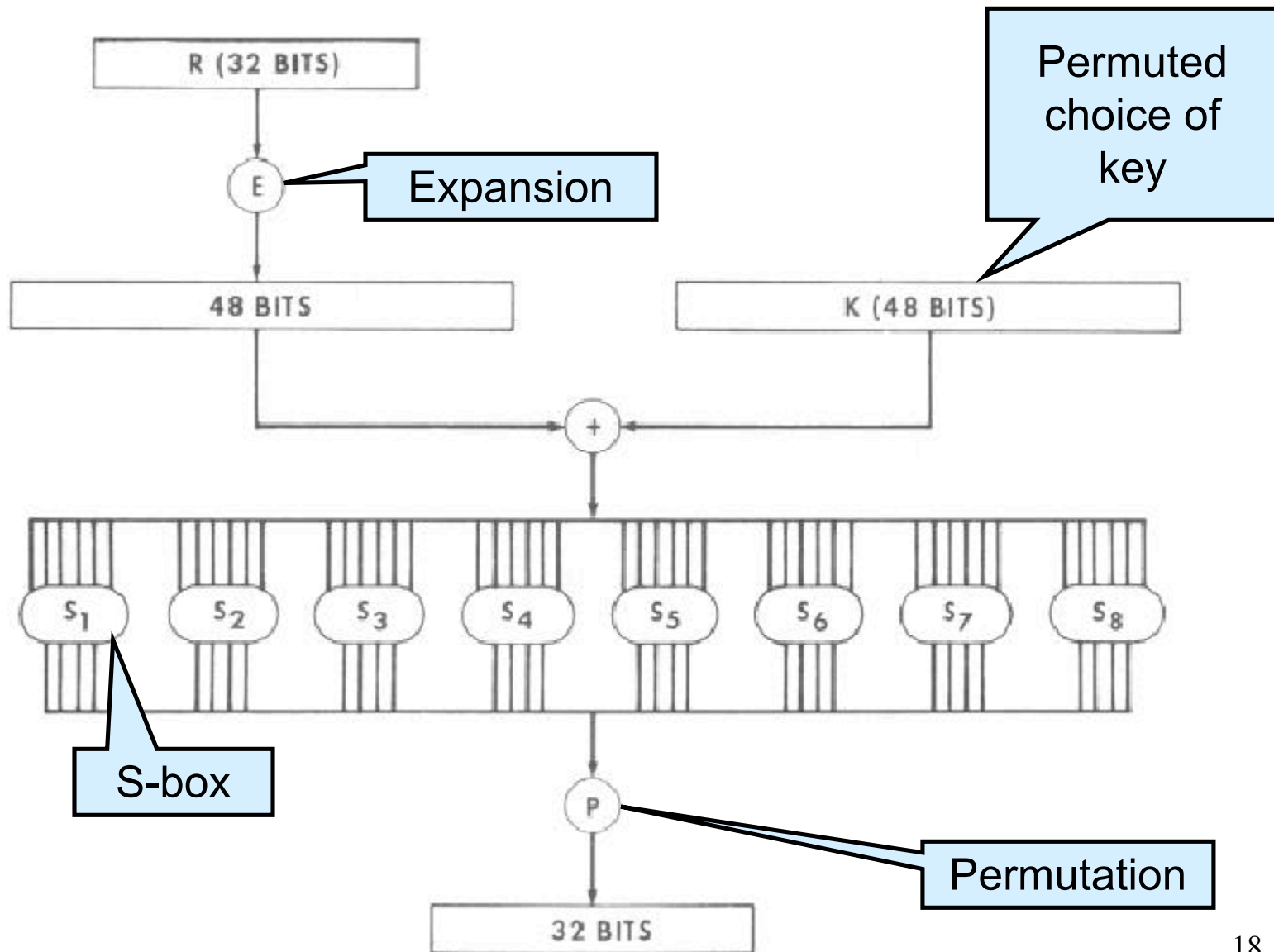
Data Encryption Standard (DES)

- Adopted as a standard in 1976
- Security analyzed by the National Security Agency (NSA)
 - <http://csrc.nist.gov/publications/fips/fips46-3/fips46-3.pdf>
- Key length is 56 bits
 - padded to 64 bits by using 8 parity bits
- Uses simple operators on (up to) 64 bit values
 - Simple to implement in software or hardware
- Input is processed in 64 bit blocks
- Based on a series of 16 *rounds*
 - Each cycle uses permutation & substitution to combine plaintext with the key

DES Encryption

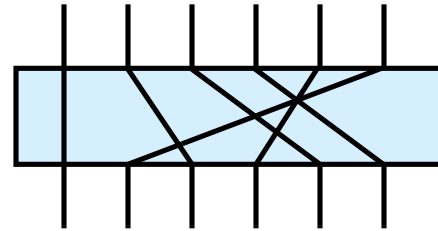


One Round of DES (f of previous slide)

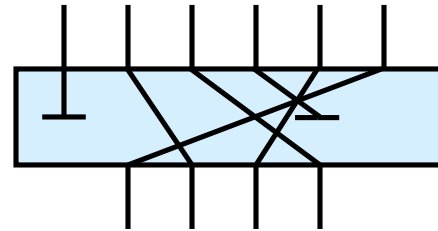


Types of Permutations in DES

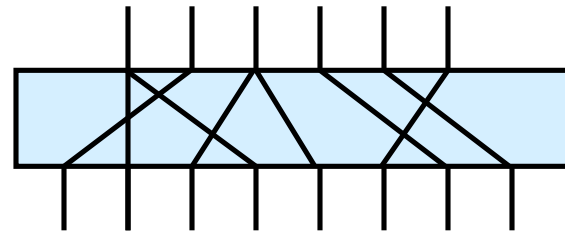
Permutation



Permuted
Choice



Expansion
Permutation



DES S-Boxes

- Substitution table
- 6 bits of input replaced by 4 bits of output
- Which substitution is applied depends on the input bits

- Implemented as a lookup table
 - 8 S-Boxes
 - Each S-Box has a table of 64 entries
 - Each entry specifies a 4-bit output

DES Decryption

- Use the same algorithm as encryption, but use $k_{16} \dots k_1$ instead of $k_1 \dots k_{16}$

- Proof that this works:

– To obtain round j from $j-1$:

$$(1) \quad L_j = R_{j-1}$$

$$(2) \quad R_j = L_{j-1} \oplus f(R_{j-1}, k_j)$$

– Rewrite in terms of round $j-1$:

$$(1) \quad R_{j-1} = L_j$$

$$(2) \quad L_{j-1} \oplus f(R_{j-1}, k_j) = R_j$$

$$L_{j-1} \oplus f(R_{j-1}, k_j) \oplus f(R_{j-1}, k_j) = R_j \oplus f(R_{j-1}, k_j)$$

$$L_{j-1} = R_j \oplus f(R_{j-1}, k_j)$$

$$L_{j-1} = R_j \oplus f(L_j, k_j)$$