Security in Computer Networks

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Audio/Video recordings of this lecture are available on-line at:

http://www.cse.wustl.edu/~jain/cse473-21/

Student Questions

1. Secret Key Encryption
2. Public Key Encryption
3. Hash Functions, Digital Signature, Digital Certificates
4. Secure Email

Not Covered:, SSL, IKE, WEP, IPSec, VPN, Firewalls, Intrusion Detection. These topics will not be included in the exam.

Note: This class lecture is based on Chapter 8 of the textbook (Kurose and Ross) and the figures provided by the authors.

Student Questions

Security Requirements

- **Integrity**: Received = sent?
- **Availability**: Legal users should be able to use.
  Ping continuously ⇒ No useful work gets done.
- **Confidentiality and Privacy**:
  No snooping or wiretapping
- **Authentication**: You are who you say you are.
  A student at Dartmouth posing as a professor canceled the exam.
- **Authorization** = Access Control
  Only authorized users get to the data
- **Non-repudiation**: Neither sender nor receiver can deny the existence of a message

Student Questions

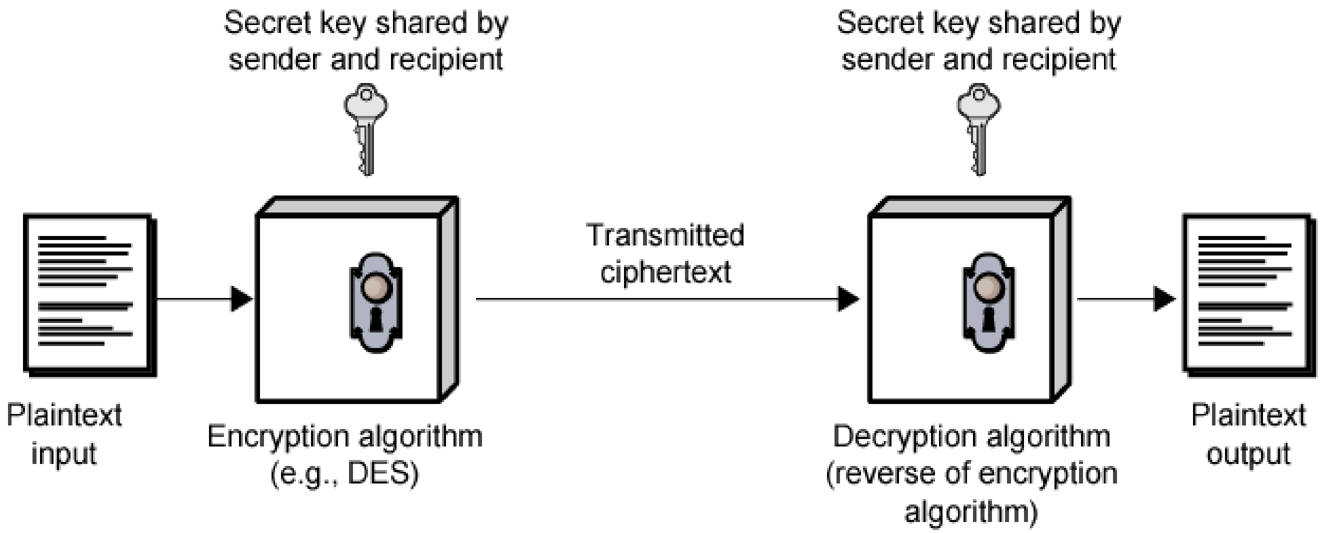
Secret Key Encryption: Overview

1. Concept: Secret Key Encryption
2. Method: Block Encryption
3. Improvement: Cipher Block Chaining (CBC)
4. Standards: DES, 3DES, AES

Student Questions

Secret Key Encryption

- Also known as symmetric key encryption
- Encrypted_Message = Encrypt(Key, Message)
- Message = Decrypt(Key, Encrypted_Message)
- Example: Encrypt = division
- 433 = 48 R 1 (using divisor of 9)



Student Questions

Secret Key: A Simple Example

- **Substitution**: Substituting one thing for another
- **Monoalphabetic**: substitute one letter for another

plaintext: abcdefghijklmnopqrstuvwxyz
↓ ↓
ciphertext: mnbvcxzasdfghjklpoiuytrewq

E.g.:

Plaintext: bob. i love you. alice

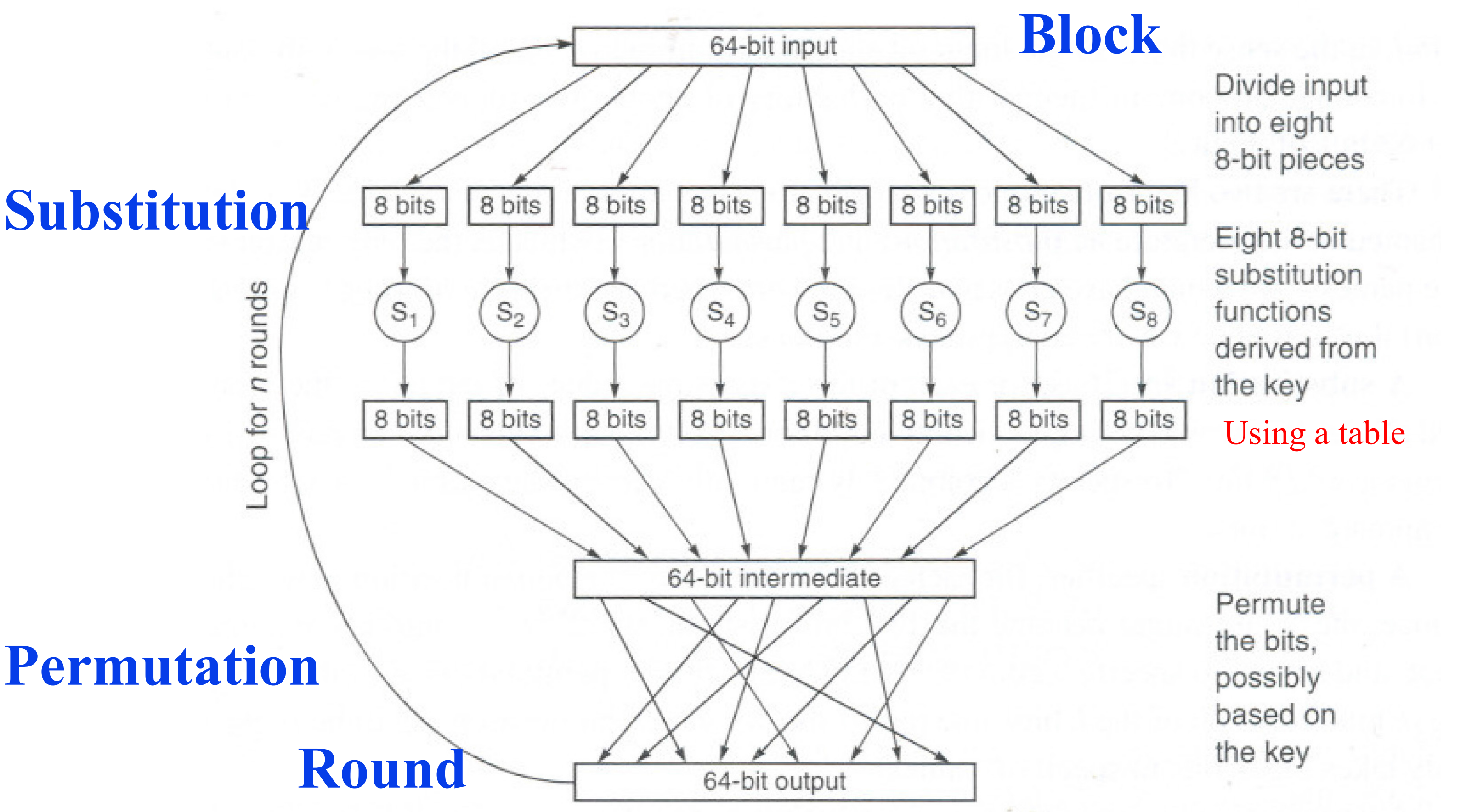
ciphertext: nkn. s gktc wky. mgsbc

- **Polyalphabetic**: Use multiple substitutions C1, C2, …
  Substitution selected depends upon the position
  ⇒Same letter coded differently in different position

Student Questions

Block Encryption

- Block Encryption



Student Questions

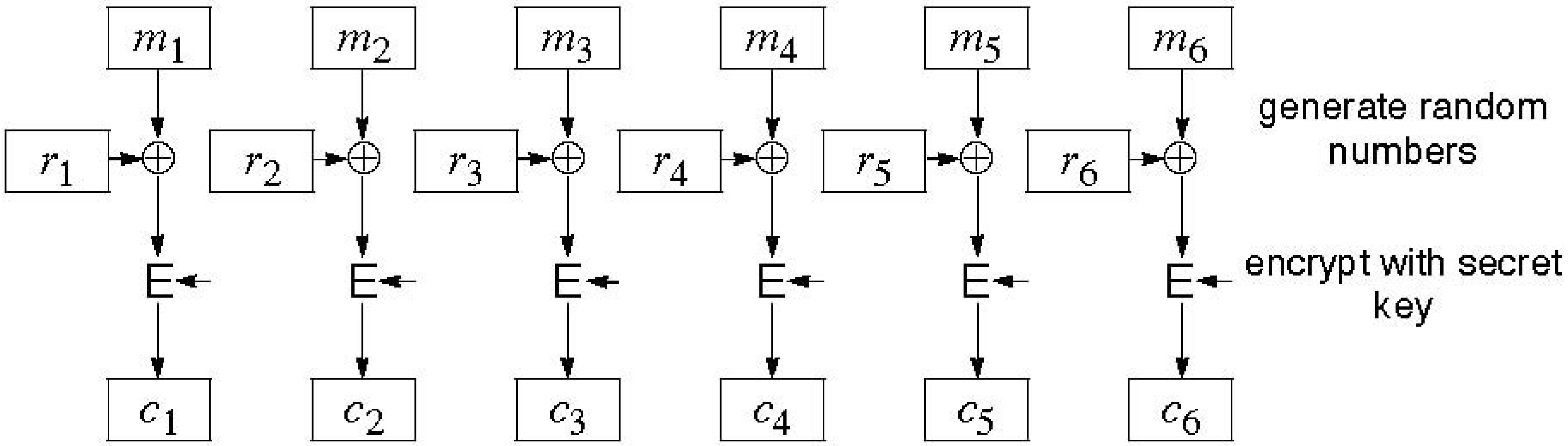
Block Encryption (Cont)

- Short block length $\Rightarrow$ tabular attack
- 64-bit block
- Transformations:
  - Substitution: replace k-bit input blocks with k-bit output blocks
  - Permutation: move input bits around.
    $1 \rightarrow 13$, $2 \rightarrow 61$, etc.
- Round: Substitution round followed by permutation round and so on. Diffusion + Confusion.
  Diffusion $\Rightarrow$ 1 bit change in input changes many bits in output
  Confusion $\Rightarrow$ Relationship between input and output is complex

Student Questions

Cipher Block Chaining (CBC)

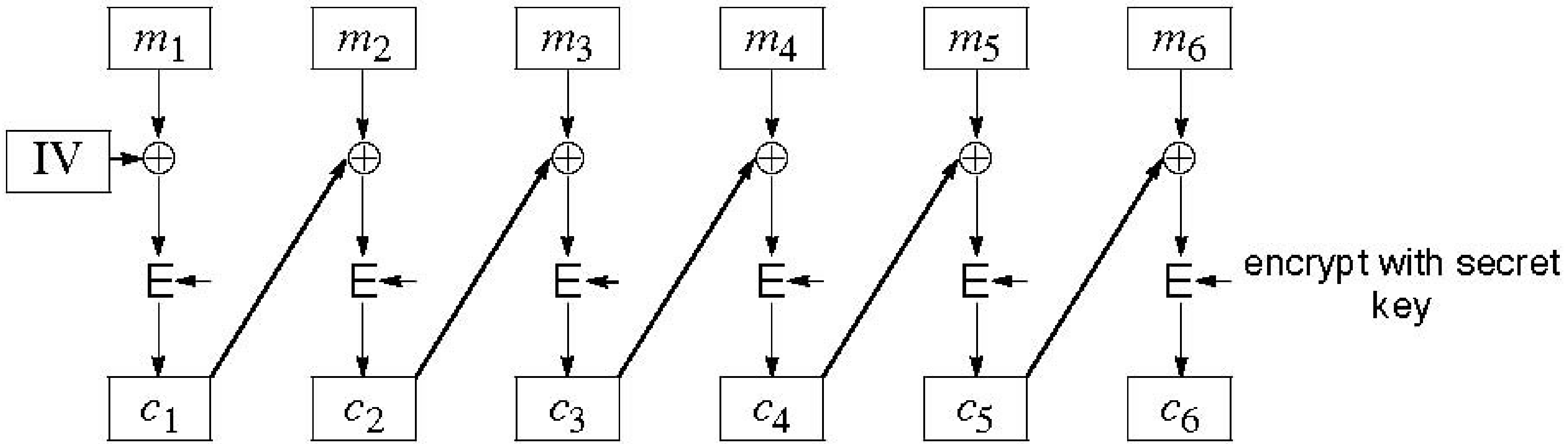
- Goal: Same message encoded differently
- Add a random number before encoding



Student Questions

CBC (Cont)

- Use C_i as random number for i+1



- Need Initial Value (IV)
- no IV ⇒ Same output for same message
  ⇒ one can guess changed blocks
- Example: Continue Holding, Start Bombing

Student Questions

Data Encryption Standard (DES)

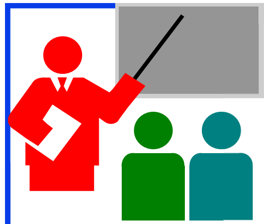
- Published by NIST in 1977
- For commercial and *unclassified* government applications
- 8 octet (64 bit) key.
  Each octet with 1 odd parity bit ⇒ 56-bit key
- Efficient hardware implementation
- Used in most financial transactions
- Computing power goes up 1 bit every 2 years
- 56-bit was secure in 1977 but is not secure today
- Now we use DES three times ⇒ Triple DES = 3DES
  Cipher Text= DES(key1, DES(key2, DES(key1, Plain Text)))

Student Questions

Advanced Encryption Standard (AES)

- Designed in 1997-2001 by National Institute of Standards and Technology (NIST)
- Federal information processing standard (FIPS 197)
- Symmetric block cipher, Block length 128 bits
- Key lengths 128, 192, and 256 bits.
  Full key is used. No parity bit in the byte.
  Memory may use 9-bits to store a byte.

Student Questions



Secret Key Encryption: Review

1. Secret key encryption requires a shared secret key
2. Block encryption, e.g., DES, 3DES, AES break into fixed size blocks and encrypt
3. CBC is one of many modes are used to ensure that the same plain text results in different cipher text.

Ref: Section 8.1, 8.2.1, Review Questions R1, R2, R6, Problems P1-P6

Student Questions

Homework 8A

- [6 points] Consider 3-bit block cipher in the Table below

Plain	000	001	010	011	100	101	110	111
Cipher	110	111	101	100	011	010	000	001

- Suppose the plaintext is 100101100.

(a) Initially assume that CBC is not used. What is the resulting ciphertext?

(b) Suppose Trudy sniffs the cipher text. Assuming she knows that a 3-bit block cipher without CBC is being employed (but doesn't know the specific cipher), what can she surmise?

(c) Now suppose that CBC is used with IV-111. What is the resulting ciphertext?

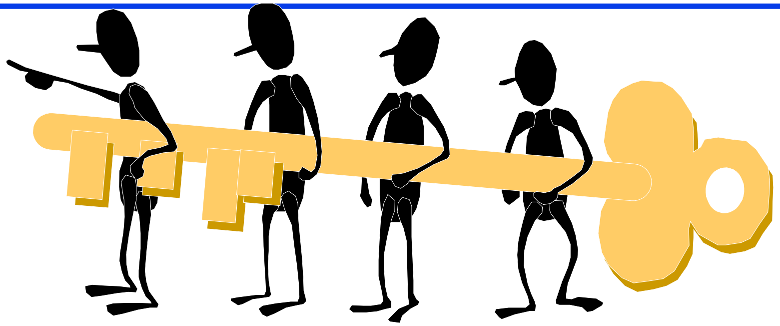
Student Questions

Public Key Encryption

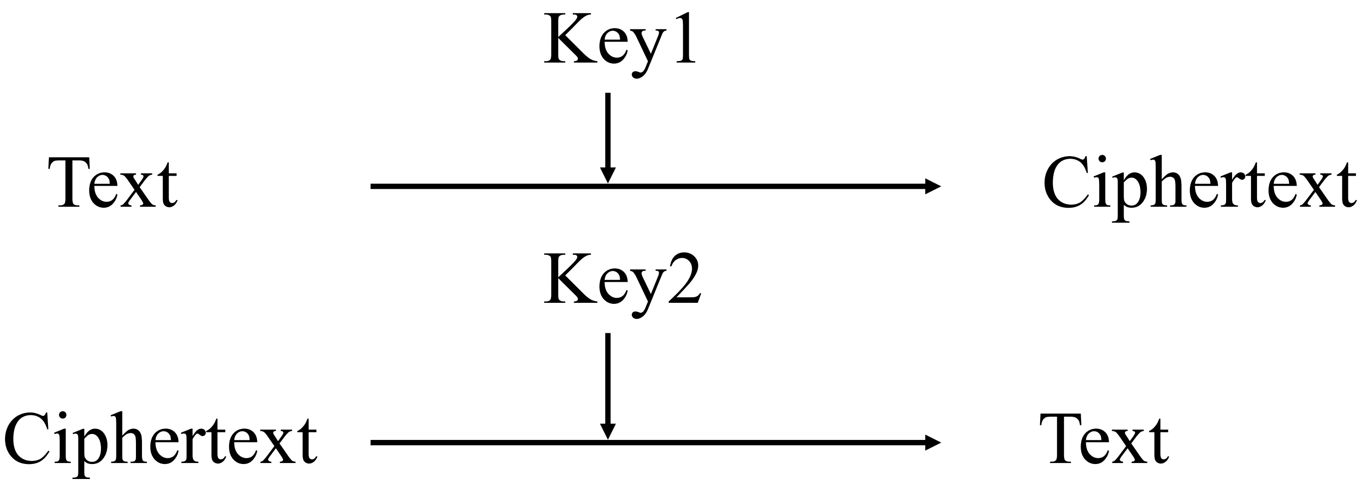
1. Public Key Encryption
2. Modular Arithmetic
3. RSA Public Key Encryption

Student Questions

Public Key Encryption



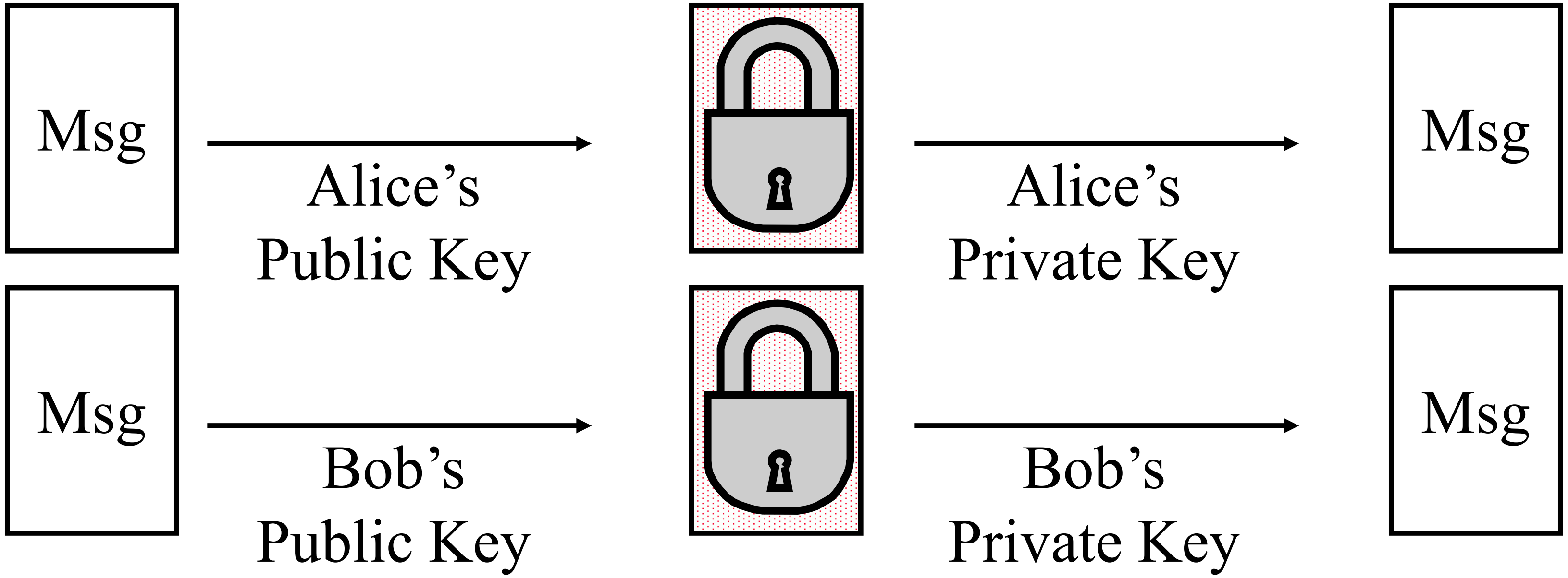
- Invented in 1975 by Diffie and Hellman
- Encrypted_Message = Encrypt(Key1, Message)
- Message = Decrypt(Key2, Encrypted_Message)



Student Questions

Public Key (Cont)

- One key is private and the other is public
- Message=Decrypt(Public_Key, Encrypt(Private_Key, Message))
- Message=Decrypt(Private_Key, Encrypt(Public_Key, Message))
- Encrypted with public key can be decrypted by private key
  Encrypted with private key can be decrypted by public key



Student Questions

Public Key Encryption Method

- Rivest, Shamir, and Adelson (RSA) method
- Example: Key1 = <3,187>, Key2 = <107,187>
- Encrypted_Message = m^3 mod 187
- Message = Encrypted_Message^{107} mod 187
- Message = 5
- Encrypted Message = 5^3 = 125 mod 187 = 125
- Message = 125^{107} mod 187 = 5
  = $125^{(64+32+8+2+1)}$ mod 187
  = {(125^{64} mod 187)(125^{32} mod 187)...
  (125^2 mod 187)(125 mod 187)} mod 187

Student Questions

Modular Arithmetic

- $xy \bmod m = (x \bmod m)\ (y \bmod m) \bmod m$
- $x^4 \bmod m = (x^2 \bmod m)(x^2 \bmod m) \bmod m$
- $x^{ij} \bmod m = (x^i \bmod m)^j \bmod m$
- $125 \bmod 187 = 125$
- $125^2 \bmod 187 = 15625 \bmod 187 = 104$
- $125^4 \bmod 187 = (125^2 \bmod 187)^2 \bmod 187$
  $= 104^2 \bmod 187 = 10816 \bmod 187 = 157$
- $125^8 \bmod 187 = 157^2 \bmod 187 = 152$
- $125^{16} \bmod 187 = 152^2 \bmod 187 = 103$
- $125^{32} \bmod 187 = 103^2 \bmod 187 = 137$
- $125^{64} \bmod 187 = 137^2 \bmod 187 = 69$
- $125^{107} = 125^{64+32+8+2+1} \bmod 187$
  $= 69 \times 137 \times 152 \times 104 \times 125 \bmod 187$
  $= 18679128000 \bmod 187 = 5$
- Need to be able to do additions to convert 107 to 64+32+8+2+1

Notation:
x = y mod z
or
x = y (mod z)
or
x mod z = y

Student Questions

RSA Public Key Encryption

- Ron Rivest, Adi Shamir, and Len Adleman at MIT 1978
- Both plain text M and cipher text C are integers between 0 and n-1.
- Key 1 = {e, n},
  Key 2 = {d, n}
- $C = M^e \bmod n$
  $M = C^d \bmod n$
- How to construct keys:
  - Select two large primes: p, q, $p \neq q$
  - $n = p \times q$
  - Calculate $z = (p-1)(q-1)$
  - Select e, such that $\gcd(z, e) = 1$; $0 < e < z$
  - Calculate d such that $de \bmod z = 1$

Student Questions

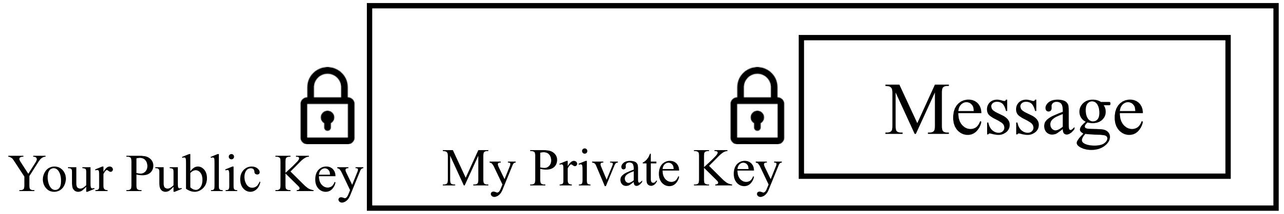
RSA Algorithm: Example

- Select two large primes: p, q, $p \neq q$
  p = 17, q = 11
- $n = p \times q = 17 \times 11 = 187$
- Calculate z = (p-1)(q-1) = 16x10 = 160
- Select e, such that gcd(z, e) = 1; $0 < e < z$
  say, e = 7
- Calculate d such that de mod z = 1
  - 160k+1 = 161, 321, 481, 641
  - Check which of these is divisible by 7
  - 161 is divisible by 7 giving d = 161/7 = 23
- Key 1 = {7, 187}, Key 2 = {23, 187}

Student Questions

Confidentiality and Non-Repudiation

- User 1 to User 2:
- Encrypted_Message
  = Encrypt(Public_Key2,
  Encrypt(Private_Key1, Message))
- Message = Decrypt(Public_Key1, Decrypt(Private_Key2, Encrypted_Message)
  ⇒ Authentic and Private



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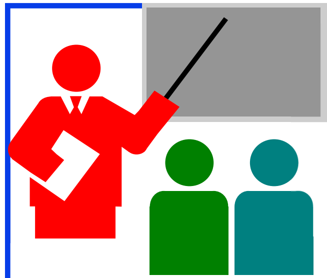


Public Key Encryption: Review

1. Public Key Encryption uses two keys: Public and Private
2. Either key can be used to encrypt. Other key will decrypt.
3. RSA public key method is based on difficulty of factorization

Ref: Section 8.2.2, Review exercises:R3, R7, Problems: P7, P9, P10

Student Questions

Homework 8B

Consider RSA with p=5, q=13

A. what are n and z

B. let e be 5. Why is this an acceptable choice for e?

C. Find d such that de=1(mod z)

D. Encrypt the message m=8 using the public key (n, e). Let c be the corresponding cipher text.

E. What is the private key. Verify that we can get the original message using the private key. Show all work.

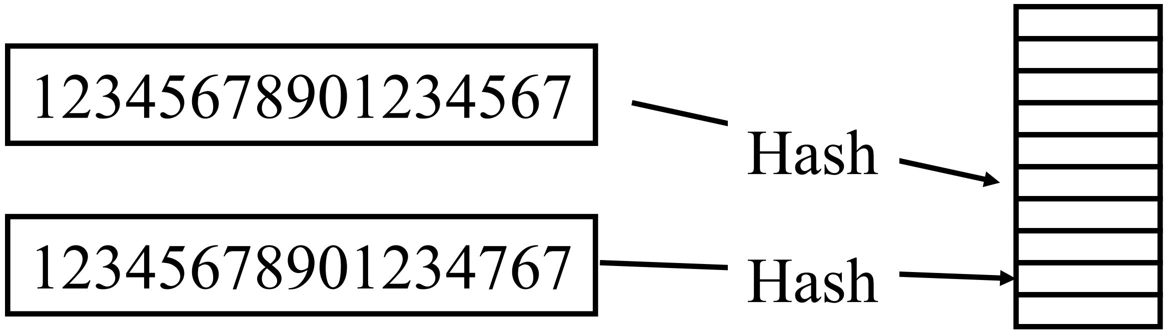
Student Questions

Hash, Signatures, Certificates

1. Hash Functions
2. MD5 Hash
3. SHA-1 Algorithm
4. Message Authentication Code (MAC)
5. Digital Signature
6. Digital Certificates
7. End Point Authentication

Student Questions

Hash Functions



Example: CRC can be used as a hash
(not recommended for security applications)

Requirements:

1. Applicable to any size message
2. Fixed length output
3. Easy to compute
4. Difficult to Invert ⇒ Can't find x given $H(x)$ ⇒ One-way
5. Difficult to find y, such that $H(x) = H(y)$ ⇒ Can't change msg
6. Difficult to find *any* pair (x, y) such that $H(x) = H(y)$
   ⇒ Strong hash

Student Questions

MD5 Hash

- 128-bit hash using 512 bit blocks using 32-bit operations
- Invented by Ron Rivest in 1991
- Described in RFC 1321
- Commonly used to check the integrity of files (easy to fudge message and the checksum)
- Also used to store passwords

Student Questions

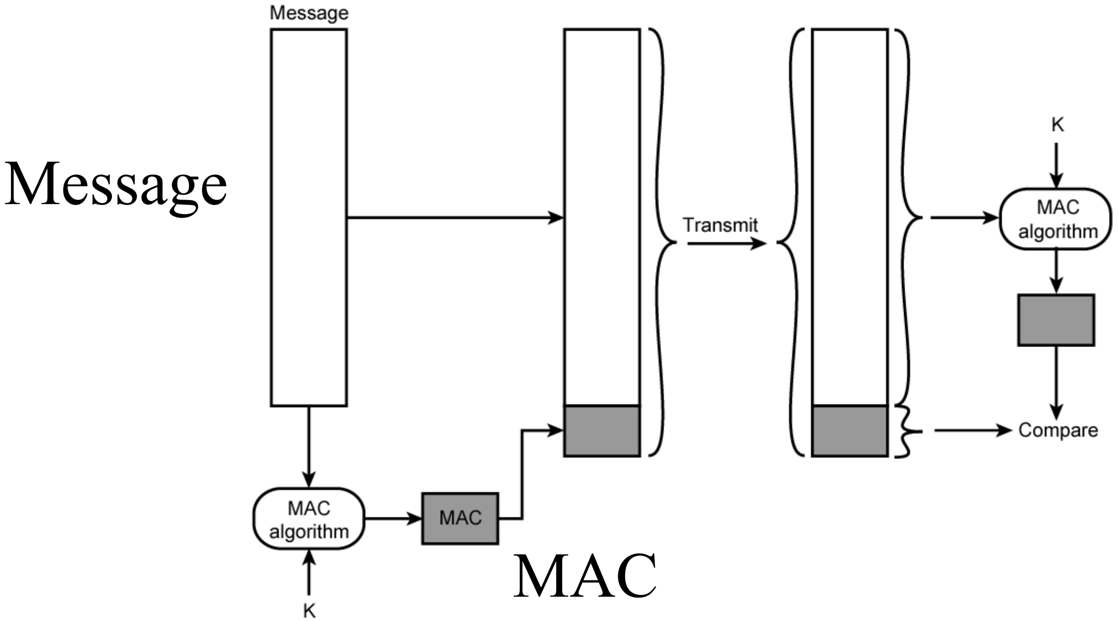
SHA-1 Algorithm

- 160 bit hash using 512 bit blocks and 32 bit operations
- Five passes (4 in MD5 and 3 in MD4)
- Maximum message size is 2^{64} bit

Student Questions

Message Authentication Code (MAC)

- Authentic Message = Contents unchanged + Source Verified
- May also want to ensure that the time of the message is correct
- $\text{Encrypt}_{\text{secret key}}$ {Message, CRC, Time Stamp}
- Message + $\text{Encrypt}_{\text{secret key}}$(Hash)
  Or, Message + $\text{Encrypt}_{\text{Source's private key}}$(Hash)



Student Questions

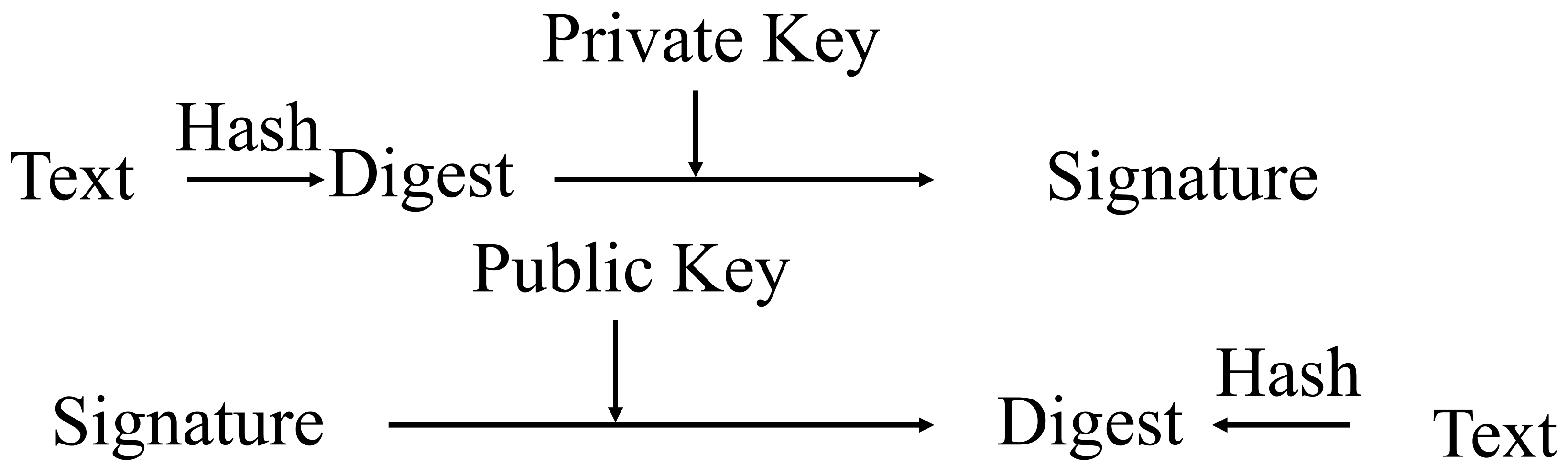
HMAC Overview

- Keyed Hash ⇒ includes a key along with message
- HMAC is a general design. Can use any hash function
  ⇒ HMAC-MD5, HMAC-AES
- Uses hash functions without modifications
- Has well understood cryptographic analysis of authentication mechanism strength

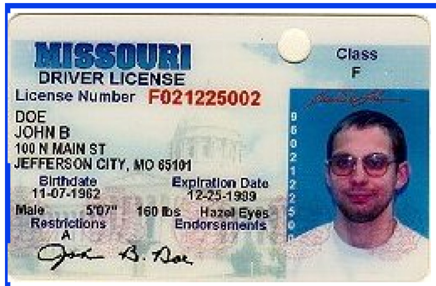
Student Questions

Digital Signature

- Message Digest = Hash(Message)
- Signature = Encrypt(Private_Key, Hash)
- Hash(Message) = Decrypt(Public_Key, Signature)
  ⇒ Authentic
- Also known as Message *authentication* code (MAC)

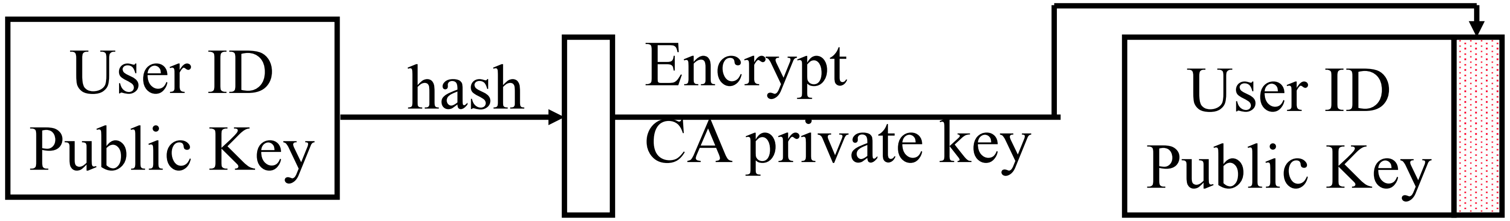


Student Questions



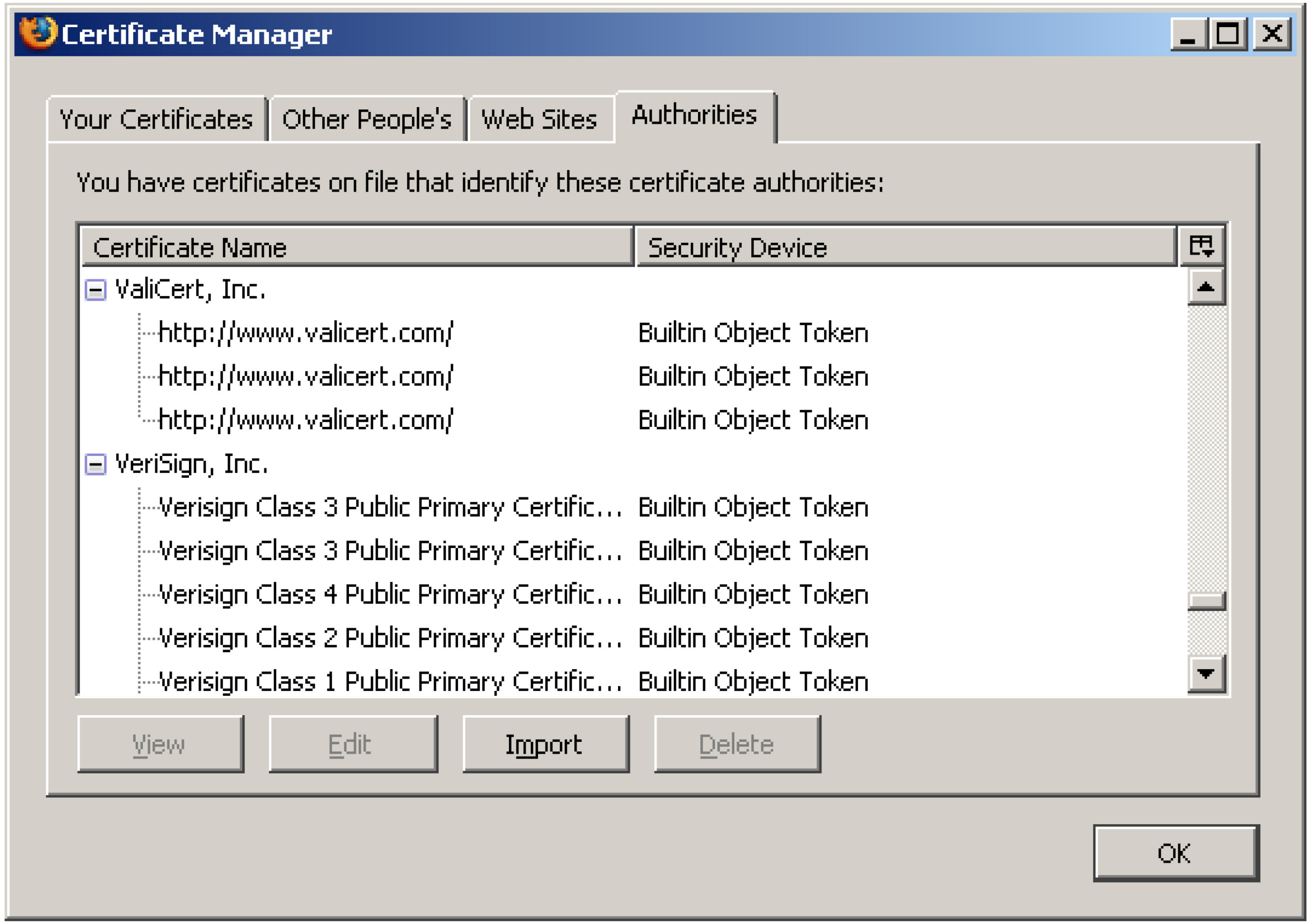
Digital Certificates

- Like driver license or passport
- Digitally signed by Certificate authority (CA) - a trusted organization
- Public keys are distributed with certificates
- CA uses its private key to sign the certificate
  $\Rightarrow$ Hierarchy of trusted authorities
- X.509 Certificate includes: Name, organization, effective date, expiration date, public key, issuer's CA name, Issuer's CA signature



Student Questions

Oligarchy Example

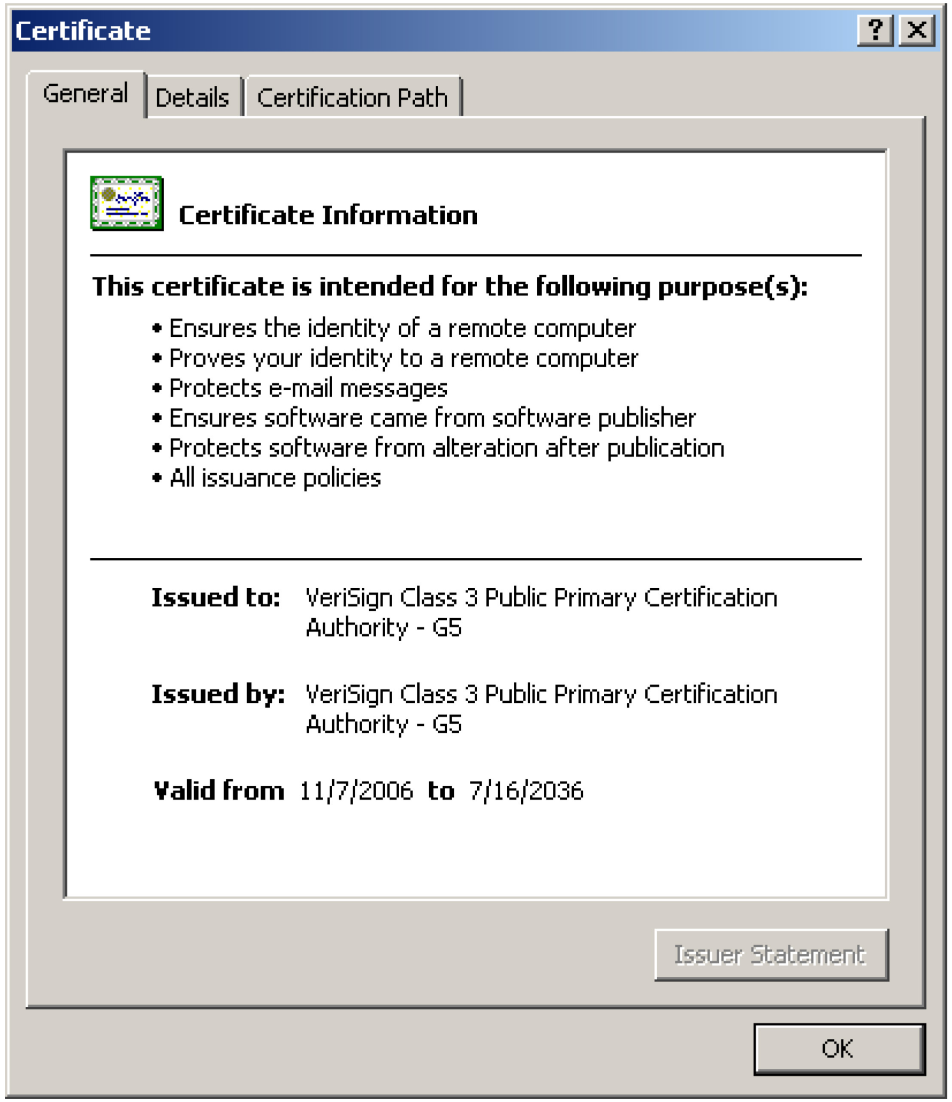


Ref: Windows: http://smallbusiness.chron.com/see-security-certificates-stored-computer-54732.html
MAC: https://superuser.com/questions/992167/where-are-digital-certificates-physically-stored-on-a-mac-os-x-machine

Student Questions

Sample X.509 Certificate

- Certmgr.msc in Windows



Student Questions

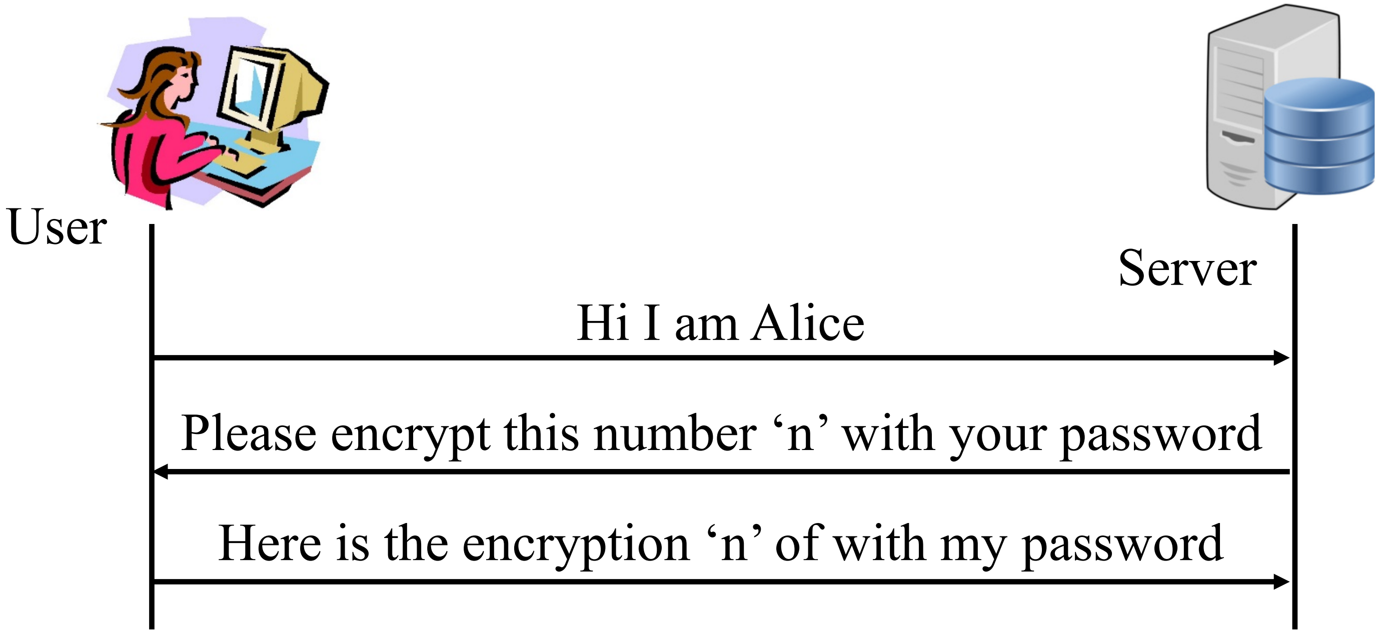
X.509 Sample (Cont)

Field	Value
Version	V3
Serial number	18 da d1 9e 26 7d e8 bb 4a 21…
Signature algorithm	sha1RSA
Issuer	VeriSign Class 3 Public Primary …
Valid from	Tuesday, November 07, 2006 …
Valid to	Wednesday, July 16, 2036 6:…
Subject	VeriSign Class 3 Public Primary …
Public key	RSA (2048 Bits)
Version	V3
Serial number	18 da d1 9e 26 7d e8 bb 4a 21…
Signature algorithm	sha1RSA
Issuer	VeriSign Class 3 Public Primary …
Valid from	Tuesday, November 07, 2006 …
Valid to	Wednesday, July 16, 2036 6:…
Subject	VeriSign Class 3 Public Primary …
Public key	RSA (2048 Bits)

Student Questions

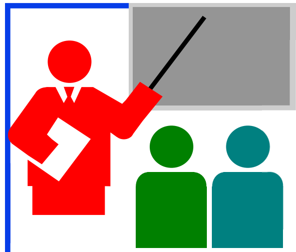
End Point Authentication

- Passwords can not be exchanged in clear
  Nonce = random **n**umber used only **once**
- Also done using certificates



Requires the server to store passwords in clear.

Student Questions



Hashes, Signatures, Certificates

1. Hashes are one-way functions such that it difficult to find another input with the same hash like MD5, SHA-1
2. Message Authentication Code (MAC) ensures message integrity and source authentication using hash functions
3. Digital Signature consists of encrypting the hash of a message using private key
4. Digital certificates are signed by root certification authorities and contain public keys

Ref: Section 8.3-8.4, Review questions R9-18

Student Questions

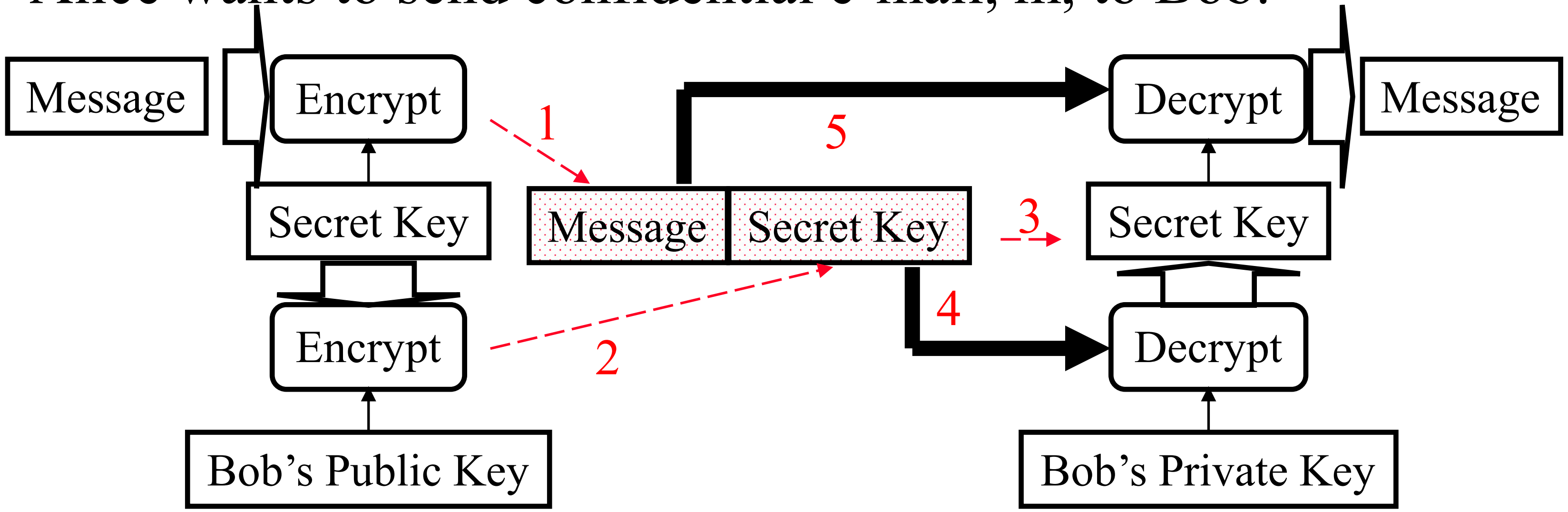
Secure Email

1. Secure E-Mail
2. Signed Secure E-Mail
3. Pretty Good Privacy (PGP)

Student Questions

Secure E-Mail

- Alice wants to send confidential e-mail, m, to Bob.



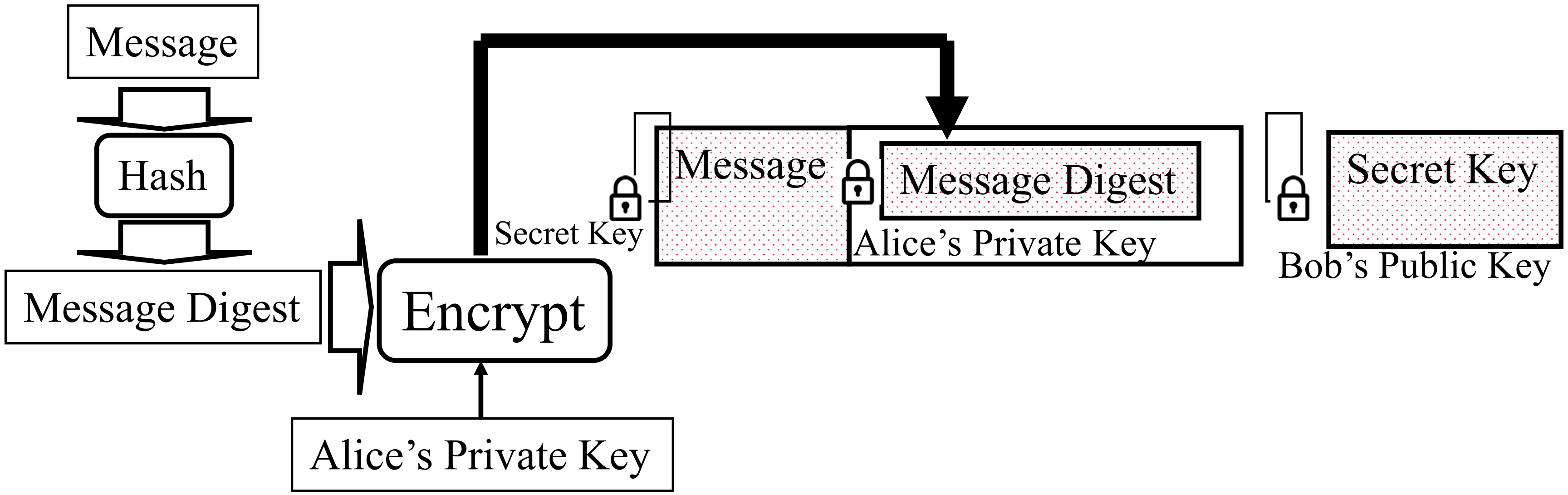
- **Alice:**
  0. Generates random *secret* key, K_S.
  1. Encrypts message with K_S (for efficiency)
  2. Also encrypts K_S with Bob's public key.
  3. Sends both $K_S(m)$ and $K_B(K_S)$ to Bob.

- **Bob:**
  4. Bob uses his private key to recover K_s
  5. Bob decrypts message

Student Questions

Signed Secure E-Mail

- Alice wants to provide secrecy, sender authentication, message integrity.



- Alice uses three keys: her private key, Bob's public key, newly created secret key
- Bob uses his private key to recover the secret key
- Bob uses Alice's public key to verify that the message came from Alice and was not changed.

Student Questions

Pretty Good Privacy (PGP)

- Used RSA and IDEA (RSA patent in US until 2000)
- V2.6.2 became legal for use within US and can be downloaded from MIT
- A patent-free version using public algorithm has also been developed
- Code published as an OCRable book
- Initially used web of trust- certificates issued by people
- Certificates can be registered on public sites, e.g., MIT
- hushmail.com is an example of PGP mail service
- OpenPGP standard [RFC 4880]
- MIME=Multipurpose Internet Mail Extenstion. Allows non-ascii characters to be encoded in ASCII

Ref: http://en.wikipedia.org/wiki/Pretty_Good_Privacy , https://en.wikipedia.org/wiki/MIME

Student Questions

Lab 8: Secure Email

[20 points] You will receive a "signed" email from the TA. Reply to this email with a "encrypted and signed" email to TA.

If outlook says "*There is a problem with the signature on the TA's message*" then click on the signature icon on the top right of the message and accept TA's certificate. The warning will go away.

- You can reply to the TA's email with a signed encrypted message. Content of the reply should be the contents of the "**Enhanced key usage**" field in your new certificate.
- Before sending the reply, on the outlook message window, Select View → Options → (More Options →) Security Settings
  Select encryption and signature. Now send the message.
- **Outlook is required** for both Windows and Mac

Student Questions

Lab 8 (Cont)

- To sign your email with a private key you need your digital certificate. To send an encrypted email you need TA's public key.
- TA's public key is attached with his/her email.
- The steps to obtain a free certificate and use it for email depend upon your email software and your operating system. Registered students of this class will receive a certificate by email.
- Instructions for Outlook on Windows 10 are as included next. If you do not have windows, you can do it using remote desktop to a Wash U windows computer.
- Instructions for Mac are similar. Further details for Mac are in the references cited below.

Ref: https://support.apple.com/guide/mail/use-personal-certificates-mlhlp1179/mac
https://knowledge.digicert.com/solution/SO6722.html

Student Questions

Lab 8 (Cont)

1. Getting your Certificate:

- You will receive a zip file in email from your certificate issuer. Unzip it.

Student Questions

Lab 8 (Cont)

2. Installing your Certificate in Outlook:

- Now open the Outlook App (not the website and follow the following click sequence:
- File → Options → Trust Center→ Trust Center Settings → Email Security → Digital IDs import/export
- Import the certificate file and enter the password that was given by Actalis. Click OK.
- Now, you can digitally sign an email by selecting the "Options" tab in the composing a message window, and clicking the "Sign" button.

Ref: https://www.thesslstore.com/knowledgebase/email-signing-support/install-e-mail-signing-certificates-outlook/

Student Questions

Lab 8 Hints (Cont)

3. Importing Other's Certificates in Outlook:

- Outlook automatically saves the certificate, if you get a signed message from your contacts.
- However, if the sender of the signed message is not in your contact database, you need to open the signed message received. In the message window, right click on the name in the "From field" and select "save as outlook contact"
- This will open a new contact window. In that window, click on the "certificates" tab.
- You will see the certificate listed there.
- Save this contact in your contacts list.
- When you reply or send email to this contact, you can enable the security options for encryption and signatures.

Student Questions

Lab 8 (Cont)

4. Sending Encrypted Emails:

- The recipient may see "There is a problem with the signature" when they receive the signed message for the first time. This is because they may not have included your certificate issuer as a trusted Certificate Authority. To fix this they need to click on the signature icon on the right-top of the message and accept the issuer's certificate. After this the problem message will go away.
- The recipient can also get a certificate and send a signed message to you. When you open that message, the recipient's public key is automatically installed in your outlook.
- After both of you have each other's public key, you can send encrypted emails to each other. You can send such messages by by selecting the dropdown menu on the "Encrypt" button (right next to the "Sign" button), and selecting "Encrypt with S/MIME".

Student Questions

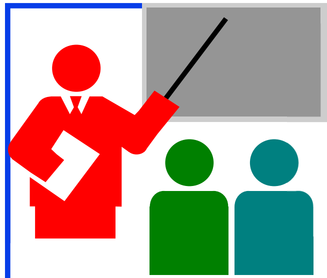
Lab 8 (Cont)

5. Examining your certificate: From the references below.

- In Windows, use Run → Certmgr.msc
- In the window that opens, look for Personal → Certificates
- Double-click on the new certificate. Go to details tab. Scroll down to find "Enhanced Key Usage". Click on it to see the results in the bottom pane. Copy and paste it to your email reply to the TA email.
- Before clicking send, remember to click options and select encryption.
- The process on MAC is in the 2nd reference below but has not been verified.

Ref: https://www.top-password.com/blog/view-installed-certificates-in-windows-10-8-7/
https://www.digicert.com/kb/code-signing/mac-verifying-code-signing-certificate.htm

Student Questions



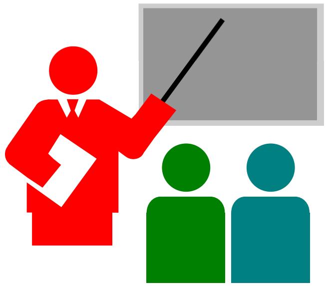
Secure Email: Review

1. Email provide confidentiality using a secret key
2. Public key and Certificates are used to:
    1. Sign the message
    2. To send the secret key

Ref: Section 8.5, Review question R19

Student Questions

Summary



1. Network security requires confidentiality, integrity, availability, authentication, and non-repudiation
2. Encryption can use one secret key or two keys (public and private)
3. Public key is very compute intensive and is generally used to send secret key
4. Digital certificate system is used to certify the public key
5. Secure email uses confidentiality using a secret key, uses certificates and public keys to sign the email and to send the secret key

Ref: Sections 8.1 through 8.5

Student Questions

Acronyms

3DES	Triple DES
AES	Advanced Encryption Standard
CA	Certificate authority
CBC	Cipher Block Chaining (CBC)
CRC	Cyclic Redundancy Check
DES	Data Encryption Standard (DES)
FIPS	Federal Information Processing standard
HMAC	Hash-based Message Authentication Code
ID	Identifier
IDEA	International Data Encryption Algorithm
IKE	Internet Key Exchange
IPSec	Secure IP
IV	Initialization Vector
MAC	Message Authentication Code
MD4	Message Digest 4
MD5	Message Digest 5

Student Questions

Acronyms (Cont)

NIST	National Institute of Standards and Technology
OCR	Optical Character Recognition
OpenPGP	Open PGP
PGP	Pretty Good Privacy
RFC	Request for Comment
RSA	Rivest, Shamir, Adleman
SHA	Secure Hash
SSL	Secure Socket Layer
TA	Teaching Assistant
US	United States
VPN	Virtual Private Network
WEP	Wired Eqivalent Privacy
XOR	Exclusive OR

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