
DISTRIBUTED SYSTEMS (COMP9243)

Lecture 11: Security

Slide 1

- ① Introduction
 - ② Cryptography
 - ③ Secure protocols and communication
 - ④ Authentication
 - ⑤ Authorisation
-
-

SECURITY IN DISTRIBUTED SYSTEMS

Related to dependability:

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Confidentiality: information disclosed/services provided only to authorised parties

Integrity: alterations can only be made in an authorised way

Availability: system is ready to be used by authorised parties

THE CAST

The Good Guys:

- Alice, Bob
- Want to communicate securely

Slide 3

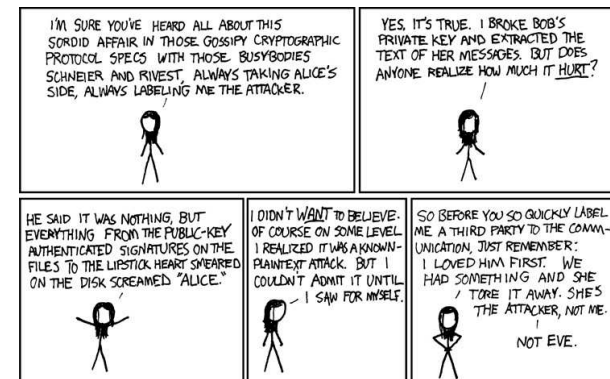
The Bad Guys:

- Eve
- The eavesdropper — tries to thwart Alice and Bob's plans

The Alice and Bob After Dinner Speech:

- google it more about Alice and Bob
-
-

Slide 4



Cryptographer:

→ Uses cryptography to convert plaintext into ciphertext

Cryptanalyst:

→ Uses cryptanalysis to attempt to turn ciphertext back into plaintext

→ Cryptanalysis: the science of making encrypted data unencrypted

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AUTHORISED ACTIONS

Security is about making sure that only authorised actions are performed in the system.

Example Actions:

→ Reading data

→ Modifying data (writing, creating, deleting)

→ Using a service

→ Managing a service

All of these could be abused if performed in unauthorised ways.

Examples?

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SECURITY POLICY

Security is a question of tradeoffs

Security Policy:

→ A statement of security requirements

→ Describes which actions entities in a system are allowed to take and which ones are prohibited

- Entities: users, services, data, machines, etc.
- Operations: read, write, send, start, stop, etc.

Example:

→ Everyone (staff and students) has an account

→ Access to course accounts must be approved

→ Only course accounts can modify grades

Anything missing?

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BREAKING SECURITY

Vulnerability:

A *vulnerability* is a weakness in the system that could potentially be exercised (accidentally triggered or intentionally exploited) to cause a breach or violation of the system's security policy.

Attack:

When a vulnerability is exercised we call this an *attack*.

Threat:

A threat is the potential for an attack, and consists of a threat-source and an exercisable vulnerability.

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SECURITY THREATS

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Interception: unauthorised party has gained access to a service or data

Interruption: service or data become unavailable, unusable, destroyed, etc.

Modification: unauthorised changing of data or tampering with a service (so that it no longer adheres to its specifications)

Fabrication: additional data or activity are generated that would normally not exist

ATTACKS

Passive vs Active Attacks:

Passive: observe data without altering it

Active: alter data

Attacking the Systems:

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- Applications
- OS
- Hardware

Attacking the Communication Channel:

- Eavesdropping
 - Masquerading
 - Message tampering
 - Denial of service
-

PROTECTING A DISTRIBUTED SYSTEM

Slide 11

Authentication: verify the claimed identity of an entity

Authorisation: determine what actions an authenticated entity is authorised to perform

Auditing: trace which entities access what

SECURITY MECHANISMS

Good Mechanisms:

Encryption: transform data into something an attacker cannot understand

- A means to implement confidentiality
- Support for integrity checks (check if data has been modified)

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Signatures and Digests support for integrity, authentication

Secure Protocols support for authentication, authorisation

Secure Communication support confidentiality and integrity

Security Architecture based on sound principles such as: small TCB, Principle of Least Privilege, support for authorisation

Less Good Mechanisms:

- Slide 13** **Obscurity:** count on system details being unknown
Intimidation: count on fear to keep you safe

DESIGNING A SECURE SYSTEM

Basic steps:

- Slide 14**
- ① Specify security policy
 - ② List threats: how can security policy be violated
 - ③ Choose mechanisms to prevent successful attacks
 - ④ Verify (formally or informally) that mechanisms foil threats

And just in case...

- Implement auditing to detect security violations due to unanticipated threats

WHY SECURITY IS HARD

Weakest Link:

- Security of a system is only as strong as its weakest link
- Need to make sure all weak links are removed
- One bug is enough
- People are often the weakest link

Complexity:

- Slide 15**
- Security involves many separate subsystems
 - Complex to set up and use
 - People won't use complex systems

Pervasiveness:

- Application level
- Middleware level
- Network level
- OS level

Distribution of Mechanisms:

- Trusted Computing Base (TCB): *those parts of the system that are able to compromise security*
 - The smaller the TCB the better.
 - May have to implement key services yourself
 - Physically separate security services from other services
- Slide 16**

Simplicity:

- Simplicity contributes to trust
- Very difficult to make a simple secure system

FOUNDATIONS

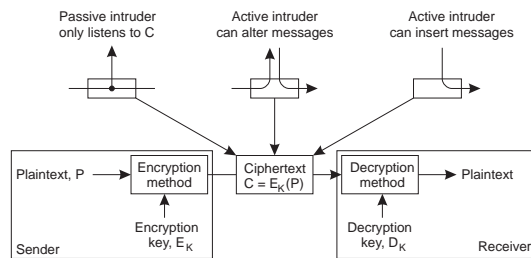
- Slide 17**
- Cryptography
 - Signatures and Digests
 - Secure Communication and Protocols

More formally:

- Slide 19**
- $E(K_E, T) = E_{K_E}(T) = \{T\}_{K_E}$: encryption of T with key K_E
 - $D(K_D, C) = D_{K_D}(C) = \{C\}_{K_D}$: decryption of C with key K_D
 - $D(K_D, E(K_E, T)) = T$ for **cognate** (matching) keys K_D, K_E

CRYPTOGRAPHY

The Basic Idea:



- Slide 18**
- Map **cleartext** (or plaintext) T to **ciphertext** (or **cryptogram**) C
 - Mapping is by a **well-known** function parameterised by a **key** K
 - T infeasible to reconstruct from C without knowledge of key

ENCRYPTION

The essence of encryption functions:

Find a function E that is easy to compute, but for which it is hard to compute T from $\{T\}_{K_E}$ without a matching decryption key K_D for K_E .

- Slide 20**
- "Hard to compute" means that it must take at least hundreds of years to reverse E without knowledge of K_D or to compute K_D
 - Such functions are known as **one-way functions**.

Cipher must be resilient to:

- Ciphertext only attacks
- Known plaintext attacks
- Chosen plaintext attacks
- Brute-force attacks

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What properties should a good cipher possess?

- Confusion: every bit of key influences large number of ciphertext bits
- Diffusion: every bit of plaintext influences large number of ciphertext bits
- Fast to compute, ideally in hardware
- Easy to use
- Not critically depend on users selecting "good" keys
- Have been heavily scrutinised by experts
- Based on operations which are provably "hard" to invert

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In practice, keys are of finite length. Consequences?

- Finite key space ⇒ susceptible to exhaustive search
- Longer keys ⇒ more time needed for brute-force attack
 - Time to guess a key is exponential in the number of bits of the key)
- ✗ Longer keys also make E and D more expensive
- Cipher must be secure against any systematic attack significantly faster than exhaustive search of key space

BASIC CIPHERS

Substitution Ciphers:

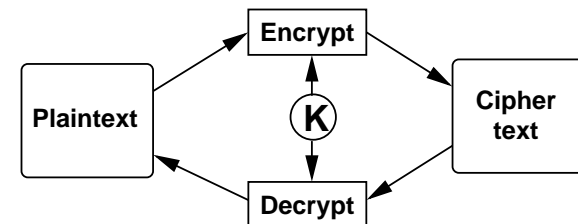
- Each plaintext character replaced by a ciphertext character
- Caesar cipher: shift alphabet x positions
 - Easy to break using statistical properties of language
- Book cipher: replace words by location of word in book
 - Knowledge of book is the key

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One Time Pads:

- Random string XORed with plaintext
- Information theoretically secure
- Random string must:
 - Have no pattern or be predictable
 - Not be reused
 - Not be known by cryptanalyst
- Key distribution problem

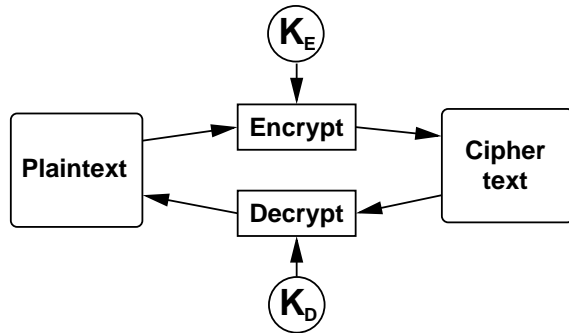
Symmetric ciphers:



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- Secret key: $K_E = K_D$
- ✓ fast ⇒ suited for large data volumes
- ✗ Secure channel is needed to establish the shared, secret key
- How many keys needed for N agents?
 - For any two agents, one key is needed
- Examples: Enigma, UNIX crypt, DES (data encryption standard), IDEA, AES

Asymmetric ciphers:



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- Due to Diffie & Hellman & Merkle (1976)
- Instead of one secret key per pair of agents, **one public/private key pair per agent**
- $K_E \neq K_D$, K_D infeasible to compute from K_E

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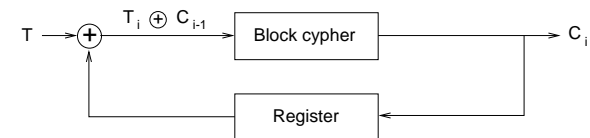
- each agent can publish **public key** $K_E =: K_P$, keep **private key** $K_D =: K_p$ secret
- Too slow to encrypt large volumes of data
- **Examples:** RSA and variants of Diffie & Hellman's original algorithm, such as ElGamal

How they work:

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- **Trap-door functions:** one-way functions with a secret exit
- Easy to compute in one direction, but infeasible to invert unless a secret (secret key) is known
- Key pair is usually derived from a common root (such as large prime numbers) such that it is infeasible to reconstruct the root from the public key

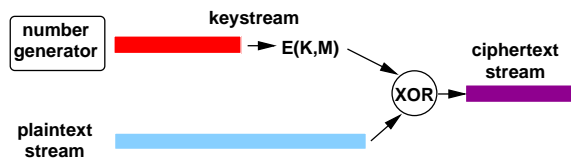
Block ciphers:



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- Encrypt **fixed-size blocks** of data (e.g., 64 bits), one at a time
- Requires some padding in the last block (weakness?)
- Blocks of ciphertext are independent (weakness?)
 - Attacker may spot repeating patterns and infer relationship to plaintext

Stream cipher:



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- Encode a given plaintext **bit by bit** (e.g., voice)
- Xor a **keystream** (sequence of 'random' bits) with the plaintext
- Security of ciphertext same as keystream
- Keystream: Output of a random number generator encoded with a block cipher algorithm
- How does the receiver reconstruct the plaintext?
 - Generate the same keystream and xor it with the ciphertext
 - requires starting value of RNG and the secret key
- Under which conditions can partial message loss be tolerated?

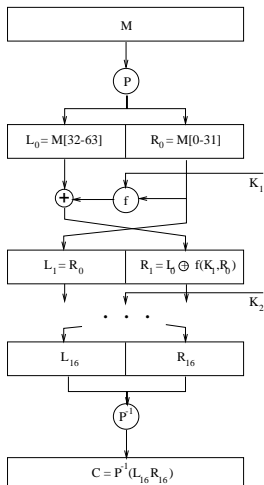
Note: This is not the same as a One Time Pad

Properties of DES:

- 1.2×10^9 bits/s in hardware (Eberle & Thacker)
- kilobits/s in software
- Heavily used in banks, government institutions, etc.
- **But** vanilla DES no longer considered safe against brute-force attack:
 - 06/1997 (DES-I), Verson: 12 weeks
 - 02/1998 (DES-II-1), [distributed.net](#): 39 days
 - 07/1998 (DES-II-2), Electronic Frontier Foundation (EFF): 3 days
 - 1999 (DES-III), [distributed.net](#) with EFF: 23h!
- "triple DES" uses $112 = 2 \times 56$ bit key to encrypt-decrypt-encrypt with standard DES (very slow)
- effective key length shorter than 112 bits (Merkle & Hellman)

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DATA ENCRYPTION STANDARD (DES)



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- Developed by IBM for US government
- Encode a 64-bit block M with a 56-bit key K
 - 16 rounds
 - initial permutation P
 - 48-bit key K_i :
 - obtained from K by rotating 1-2 bits each step
 - encryption step function f :
 - transpose and partially duplicate 32 bits of R yielding 48 bits
 - XOR with key
 - substitute/reduce number bits to 32 (S-box)

OTHER SYMMETRIC CIPHERS

International Data Encryption Algorithm (IDEA):

- Uses 128-bit key to encrypt 64-bit blocks
- Approximately three times as fast as DES
- Same function for encryption and decryption (like DES)

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Advanced Encryption Standard (AES):

- Defined in 2001, to replace DES
- The algorithm *Rijndael* (Daemen & Rijmen) was selected from a set of submissions and publicly reviewed
- Variable block and key length; specification 128, 192, or 256 bit keys and 128, 192 or 256 bit blocks
- Block and key length can be extended to multiples of 32 bit

RSA

Asymmetric (public key) cipher by Rivest, Shamir and Adelman Uses very large primes.

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- ① Choose two primes $P, Q > 10^{100}$
- ② $N = PQ; Z = (P - 1)(Q - 1)$
- ③ Choose K_E relatively prime with Z
- ④ Determine K_D such that $K_E K_D = 1 \pmod Z$
- ⑤ Encrypt k bits, $2^k < N$: $\{T\}_{K_E} = T^{K_E} \pmod N$
- ⑥ Decrypt k bits: $\{C\}_{K_D} = C^{K_D} \pmod N$

Properties of RSA:

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- Slow (kilobits/s even in hardware)
- Easy to establish secure channel (distribute keys)
- $\{\{T\}_{K_E}\}_{K_D} = \{\{T\}_{K_D}\}_{K_E} = T \forall T : 0 \leq T \leq N$
 - Can be used for digital signatures
- Secure because factoring large numbers is computationally hard:
 - No proof of this
 - Recently key of ≈ 500 bits broken by brute force
 - Factoring shown to be polynomial on quantum computers

DIGITAL SIGNATURES & DIGESTS

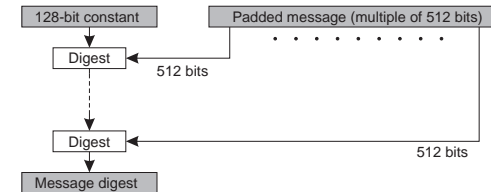
Cryptographically ensure message integrity and authenticate originator.

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How can we check whether a message has been altered?

- Secure digest or hash
- Fixed-length value condensing information in the message
- Given message M and hash $H(M)$, it must be very hard to find M' with $H(M) = H(M')$
- If hash $H(M)$ is the same after transmission, message is unaltered with very high likelihood

Hash functions:



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- Not unlike encryption functions, but not information preserving
- Most widely used algorithms: MD5 and SHA
- Rivest's MD5 algorithm: 128-bit digest; more efficient than SHA
- SHA is standardised, more secure (produces 160-bit digest)
- Any symmetric encryption algorithm could be used as hashing function with cipher block chaining, but
 - less efficient and
 - requires use of a key

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Must be resilient against birthday attacks:

- Birthday paradox: chance that out of 23 people two have same birthday is 50%
- Expect hash collision after evaluating $1.2k^{1/2}$ inputs (k is number of possible values)
- **Birthday attack**: find two documents with matching hashes
- Given an innocent message $M1$ find a malicious message $M2$ that collides with it
- **Design hash such that k is really big!**

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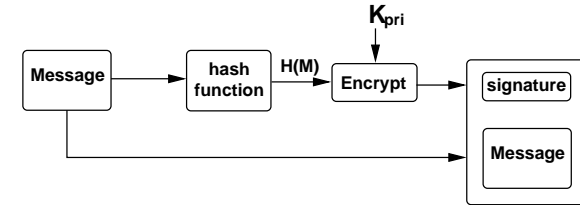
How can we make the digest tamper resistant?

- Transmitting the digest alongside the message doesn't prevent tampering
- Encrypt the digest using public key cryptography
- Sender encrypts the digest with private key

Digital Signature:

→ How to verify who sent the message

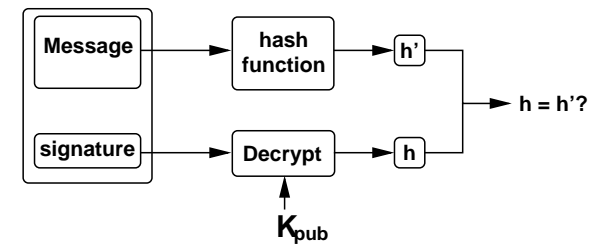
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→ Given a message M and sender private key K_{pri} , signed message:

$$(M, \{H(M)\}_{K_{pri}})$$

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- Recipient uses matching public key K_{pub} to recover digest
- Compare recovered digest to result of computing $H(M)$
- If same, sent message must be unaltered and sender the owner of K_{pri}

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What guarantees are provided by a signed document in a sealed envelope?

- **Authentication:** receiver wants to be sure of the sender's identity
- **Confidentiality:** transmitted information is kept private
- **Integrity:** message could not have been altered
- **Non-repudiation:** sender cannot credibly deny having signed the message

SECURE PROTOCOLS

Protocol: rules governing communication

Security protocol: protocol that performs a security-related function (usually authentication)

Goal: Survive malicious attacks:

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- Lies
- Modifying data
- Injecting data
- Malicious behaviour

Threat Assumptions:

- Can communication channel be intercepted?
- Can data stream be modified?
- Are participants malicious?

HOW TO BUILD A CRYPTOGRAPHIC PROTOCOL

Use:

- encryption
- secure digest
- signatures
- random number generators

Protocol mechanisms:

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- Challenge-Response
 - nonce – used to uniquely relate two messages together
- Ticket – secured information to be passed to another party
- Session keys – for secure communication

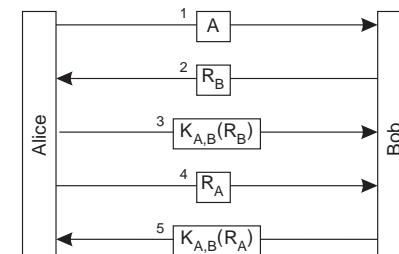
Principles:

- A message must contain all relevant information
- Don't allow parties to do things identically
- Don't give away valuable information to strangers

A SIMPLE PROTOCOL

Authentication

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HOW TO BREAK A PROTOCOL

Man-in-the-Middle:

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- Take on the role of Alice to Bob and Bob to Alice
- Alice → Eve: challenge
- Eve → Bob: challenge
- Eve ← Bob: response
- Alice ← Eve: response

Reflection:

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- Use Alice to respond to Alice's challenge
- Alice → Eve: challenge
- Alice ← Eve: challenge
- Alice → Eve: response
- Alice ← Eve: response

Replay:

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- Re-use Bob's old message to respond to Alice's challenge
- Alice → Bob: challenge
- Alice ← Eve ← Bob: response
- Alice → Eve: challenge
- Alice ← Eve: response

Message Manipulation:

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- Change the message from Alice to Bob
- Alice sends: let's meet at 3pm by the bridge
- Eve intercepts and changes
- Bob receives: let's meet at 2pm by the oak

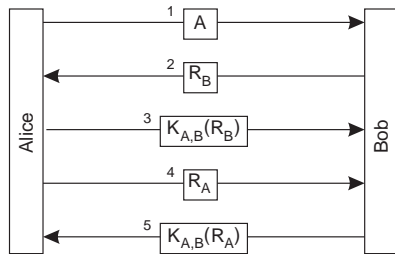
Changed Environment/Assumptions:

- Bob is no longer trustworthy
- Bob sells Alice's secrets to the tabloid press!

A SIMPLE PROTOCOL: REVISITED

Authentication

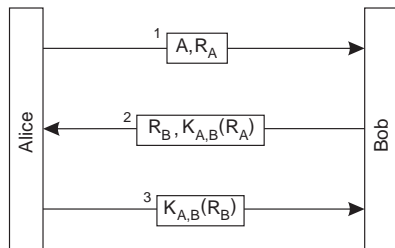
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Vulnerable?

OPTIMISING THE PROTOCOL

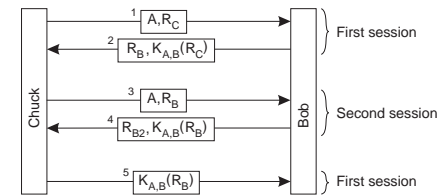
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Oops!

→ Vulnerable to reflection attack

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KEY DISTRIBUTION

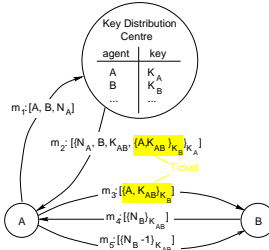
A set of keys provides a **secure channel** for communication.

How does the secure channel get established in the first place?

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- Use separate channel to establish keys
- Use key distribution protocols
- Protocols vary depending on whether symmetric or asymmetric encryption is used
- Often symmetric keys are communicated over a channel using an asymmetric cipher

DISTRIBUTION OF SYMMETRIC KEYS (NEEDHAM-SCHROEDER)



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- Central **key distribution centre** D
- Each agent A shares a (symmetric) key K_A with D
- A wants to communicate with B , asks D for **session key** K_{AB}
- After key distribution protocol, both A and B know that they share a key provided by D .

Properties of the symmetric key distribution protocol:

- Ticket and challenge implicitly **authenticate** A and B .
- Nonce and challenge protect against replay attacks.
- D is centralised resource (hierarchical scheme possible).
- Every agent must **trust** D .
- D maintains highly sensitive information (secret keys), compromising D compromises all communication.
- Large number of keys required (one per pair of agents), manufactured by D on-the-fly.
- D must take care to make key sequence non-predictable.

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Any vulnerabilities?

SECURE COMMUNICATION

Properties of a Secure Channel:

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- Authentication
- Message confidentiality
- Message integrity

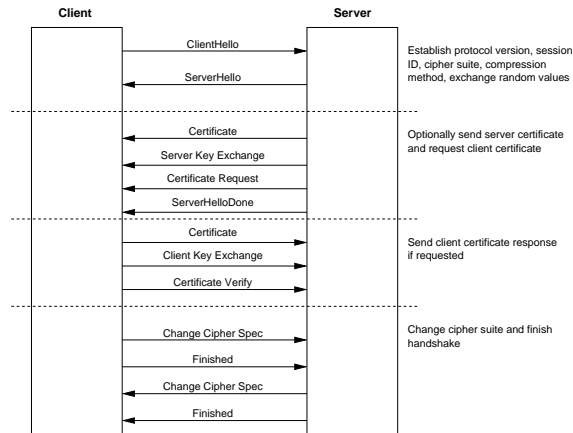
EXAMPLE: SSL (AND TLS)

Secure Socket Layer:

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- Application level protocol for secure channel
- Handshake protocol: establish and maintain session
- Record protocol: secure channel
- Flexible: can choose ciphers to use
- Most widely used to secure HTTP (https: URLs)
- TLS (Transport Layer security): IETF standard based on SSL 3.0
- TLS 1.0: RFC 2246

SSL Handshake Protocol:



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SECURE GROUP COMMUNICATION

Two types:

Confidential group communication:

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- All group members share the same secret key
- ✗ Need to trust all members
- Separate keys for each pair
- ✗ Scalability problem
- Public key cryptography
- ✗ Everyone knows each others keys

Secure replicated servers:

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- Secure Replicated Servers: protecting from malicious group members
- Collect responses from all servers and authenticate each
- Not transparent
- Secret sharing: All group members know part of a secret. Recipient combines answers from k members, decrypts with special decryption function D . If successful: these k members are honest. If not: try other combination of answers.

AUTHENTICATION

Verify the claimed identity of an entity (principal)

Authentication Requires:

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- Representation of identity
 - Unix user id, email address, student number, bank account
- Some way to verify the identity
 - Password, reply to email, student card, PIN
- Different levels of authentication

Credentials:

- *Speaks for* a principal
- Example: certificate stating identity of a principal
- Combine credentials
- Role-based credentials

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Delegation:

- Entitles one principal to perform an action with the authority of another
- Associated with right restriction
- Delegation certificate, capabilities

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Approaches to Authentication:

- Shared secret key:** challenge and response encoded with shared secret key
- Key distribution centre:** keys stored at KDC, never sent over network
- Public key:** exchange session key encoded with public keys
- Hybrid:** use public keys to set up a secure channel and then authenticate

KERBEROS

- Commercial authentication system developed at MIT
- Based on Needham and Schroeder protocol
- Integrates symmetric key encryption, distribution and authentication into commercial computer systems.

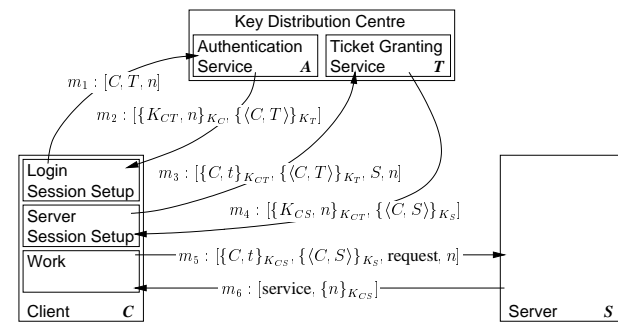
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Assumptions:

- secure central server
- insecure network
 - never transmit cleartext passwords
- insecure workstations (shared between users)
 - hold user passwords on workstations for very short periods only
 - hold no system keys on workstations

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Kerberos Authentication:



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- Central KDC contains
 - **Authentication service *A***,
knows all user logins and their passwords (secret keys) as well as identity and key of *T*;
 - **Ticket granting service *T***,
knows all servers and their secret keys
- Kerberos protocol has three phases:
 - ① login session setup (user authentication)
 - ② server session setup (establishing secure channel to server)
 - ③ client-server RPC
- Uses time-limited tickets

DISTRIBUTION OF PUBLIC KEYS

Major weakness of Needham-Schroeder and Kerberos:

- Key distribution centre as a central authority
- Compromised keys can be used to decrypt past communication

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Public Key Infrastructure (PKI):

- Public keys can be exposed without risk
- Distribution centre only establishes link between identities and public keys

Certificates and certification authorities:

- A **certificate** links an identity with a public key
- Distribution centres are called **certificate servers** or **certificate directories**

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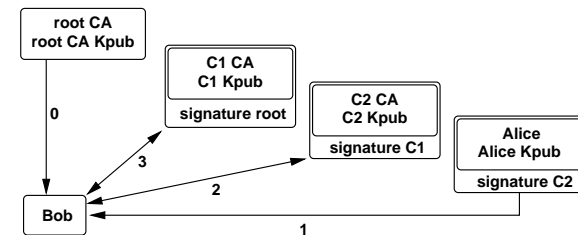
How to communicate certificates to clients?

- Secure channel between certificates server and client?
- Digital signatures establish the validity of certificates
- Formatted according to X509.1 standard or PGP format

Whose signature?

- **Certification authorities** sell certification as a service
- Alternatively, **web of trust** avoids any central authority

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Checking of certificates is recursive:

- To establish trust in Alice's certificate signed by *C₂*, Bob may need to obtain *C₂*'s certificate
- Bob uses the public key of *C₂* to validate Alice's certificate
- *C₂* is signed by *C₁*
- This may lead to a **chain of certificates**
- Terminated by self-signed certificate of a **root certification authority** (who Bob trusts)

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Are certificates valid forever?

- Certificates may have an expiry date to reduce risk of security breach
- After a certificate expires, a new one must be generated and signed
- Alternatively, certificates may be revoked
- Revocation is only effective if receiver regularly checks the certificate server

HYBRID: SSH1 AUTHENTICATION

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Client	Server
Connect to server	
	SSH version
SSH Version	
	public host key: H public server key: S bulk data ciphers: 3DES, Blowfish Authentication methods: RSA, password
data cipher: 3DES session key: H(S(K))	
	encrypted with K: OK

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Client:encrypted with K	Server:encrypted with K
login:alice	
	need authentication for alice
RSA authentication: public key P	
	server checks authorized_keys not found NO
password	
	server checks password matches SUCCESS

AUTHORISATION AND ACCESS CONTROL

Determine what actions an authenticated entity is authorised to perform

Access Rights:

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- The rights required to access (perform an operation on) a given resource

Two aspects:

Access Control: verify access rights

Authorisation: grant access rights

Ensuring that authorisation and access control are respected

Non-distributed Protection:

- Global mechanisms
- Global policies
- Examples:
 - Users
 - File permissions
 - Separate address spaces

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Distributed Protection:

- Service specific
 - Web servers and .htaccess: authentication, access control
 - Application specific
-

Design considerations in a protection system:

- Propagation of rights:
 - Can someone act as an agent's proxy?
 - Restriction of rights:
 - Can an agent propagate a subset of their rights?
 - Amplification of rights:
 - Can an unprivileged agent perform some privileged operations?
 - Revocation of rights:
 - Can a right, once granted, be remove from an agent?
 - Determination of object accessibility
 - Who has which rights on an object?
 - Determination of agent's protection domain
 - What is the set of objects an agent can access?
-

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ACCESS CONTROL MATRIX

Subjects	Objects			
	O_1	O_2	O_3	O_4
S_1	terminate	wait, signal, send	read	
S_2	wait, signal, terminate			read, execute write, control
S_3		wait, signal, receive		
S_4	control		execute	write

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- Access permissions of a given subject to a given object
 - Specifies allowed operations
-

Properties of the access matrix:

- Rows define subjects' protection domains
 - Columns define objects' accessibility
 - Dynamic data structure: frequently changes
 - permanent changes (e.g. chmod)
 - temporary changes (e.g. setuid flag)
 - Matrix is very sparse with many repeated entries
 - usually not stored explicitly
-

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Access control lists (ACLs):

Object	Subjects			
	S_1	S_2	S_3	S_4
/etc/passwd	read	read, write	-	read

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- Column-wise representation of the access matrix
- Each object associated with a list of (subject, rights) pairs
 - requires explicit authentication
- Usually supports concept of group rights (domain classes) (granted to each agent belonging to the group)
- Often simplified to a simple fixed-size list (e.g., UNIX *user-group-others* or VMS *system-owner-group-world*)
- Can have negative rights as well (e.g., to simplify exclusion from groups)

Properties of ACLs:

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- Propagation: (e.g., owner can `chmod`)
- Restriction: meta-right
- Amplification: (e.g., `setuid`)
- Revocation: remove from ACL
- Object accessibility: explicit in ACL
- Protection domain: hard (if not impossible)

Capabilities:

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- An element of access matrix
- Capabilities list (C-list) associated with each subject, which defines a protection domain
- Each capability can confer a single or a set of rights
- Capabilities can confer negative rights
- Capabilities must be protected against forgery and theft
- Capability implies an object name:
 - prima facie evidence of access permission
 - independent of authentication
 - don't need to trust intermediary

Properties of capabilities:

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- Propagation: copy capability (but need to be careful about confinement)
- Restriction: may be supported by derived capabilities
- Amplification: may have amplification capabilities
- Revocation: difficult, requires invalidation
- Object accessibility: hard (if not impossible)
- Protection domain: explicit in C-list

Three basic approaches to making caps tamper-proof:

→ Tagged capabilities:

- protected by hardware (tag bit)
- controlled by OS (only kernel can turn on tag bit)
- used in most historical capability systems (Plessey 250, CAP, Hydra, System/38)

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→ Partitioned (segregated) capabilities:

- protected by OS: Capabilities kept in kernel space
- used in Mach, Grasshopper, EROS

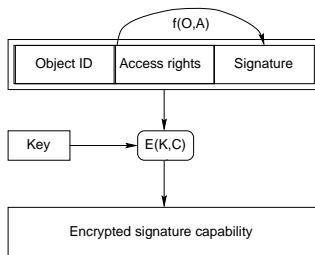
→ Sparse capabilities:

- protected by sparseness (obscurity)
- used in Monash Password Capability System, Amoeba, Mungi

Signature capabilities:

→ "First Migration Scheme": Designed for distributing tagged capabilities

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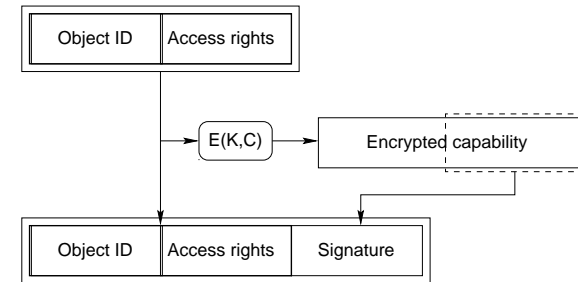


- ✓ tamper proof via encryption with **secret kernel key**
- ✓ can be freely passed around
- ✗ need to decrypt on each validation
- ✗ users do not know which object a capability refers to
- ✗ secret kernel key

Signature capabilities:

→ "Second Migration Scheme"

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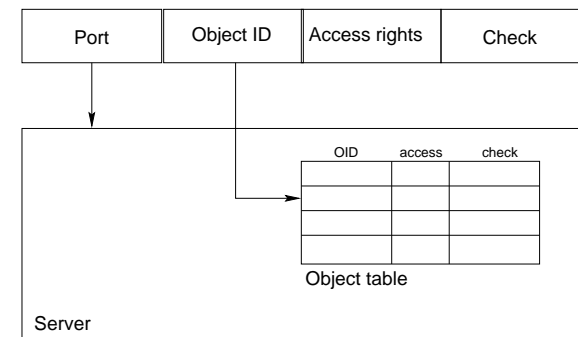


→ makes object ID visible, yet still tamper proof

Amoeba's capabilities:

→ Amoeba is a server-based distributed OS using sparse capabilities

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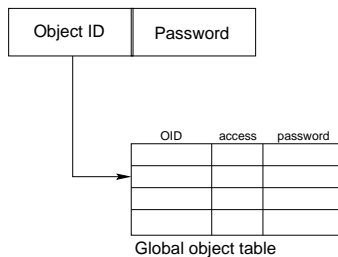
Properties of Amoeba's capabilities:

- Port identifies server (kernel caches server location)
- Port IDs are large (48-bit) sparse numbers (knowing port implies send rights)
- Server uses OID to look up rights, check fields to compare
- Original ("owner") capability has all rights.
 - **Restriction** by asking server to derive lesser capability
 - **Revocation** requires asking server to change check field ⇒ revokes access for *all* holders
 - **Amplification** by server

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Password capabilities:

- Invented for Monash U's Password Capability System
- "Random" bitstring is password, not derived from other parts of capability.
- Validation requires checking against global object table.



FIREWALLS

Properties:

- When communicating with untrusted clients/servers
- Disconnects part of system from outside world
- Incoming communication inspected and filtered

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Two types:

- Packet-filtering gateway
- Application-level gateway

Three Myths of Firewalls:

- ① We've got the place surrounded
- ② Nobody here but us chickens
- ③ Sticks and Stones may break my bones, but words will never hurt me

HOW TO BREAK SECURITY?

Encryption:

- find weaknesses in algorithms
- find weaknesses in implementations
- attack underlying intractable problem
- brute force

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Protocols:

- try man-in-the-middle, reflection attacks
- find vulnerability in implementation

Authentication:

- find keys or passwords
- social engineering

Authorisation and Access Control:

- find and exploit bugs to escalate privileges

READING LIST

- Slide 89** **Ross J. Anderson** Security Engineering: A Guide to Building Dependable Distributed Systems. Covers many pitfalls of building secure systems, with many real-world examples.