

Security mechanisms

- Introduction (Shay 7.1)
- Encryption (Shay 7.2-7.4)
- Authentication (Shay 7.4-7.5)

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Security 101

Properties of secure data: **CIA**

- **C**onfidentiality: no unauthorised user can read
- **I**ntegrity: no unauthorised user can write
- **A**vailability: all authorised users can read and write

Confidentiality - provided by *encryption*

Integrity - provided by *authentication* and *cryptographic signature*

Availability - means preventing *denial of service attacks*

For now we'll consider techniques for encryption and authentication.

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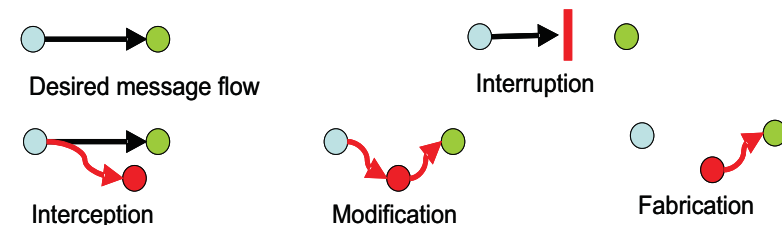
Security functions

- The **Gold Standard**, and some **additional functions**:
 - **A**uthentication: are you who you say you are?
 - All claims to identity can be verified.
 - **A**uthorisation: who is permitted to do which operations to what?
 - Users can't increase their own authority.
 - **A**uditing: what has happened on this system?
 - System administrators can investigate problems.
 - **I**dentification: what human (or object) is this?
 - Different from authentication (a proof of an identity) or authorisation (a decision to allow an activity).
 - **N**on-repudiation: can you prove this event really did happen?
- To learn more: Lampson, "Computer Security in the Real World", *IEEE Computer* 37:6, June 2004.

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Network attacks (Stallman)

- **Modification** or *man in the middle*: an attacker changes a message;
- **Interruption** or *denial of service*: an attacker prevents delivery, often by floods of rubbish packets;
- **Fabrication** or *spoofing*: an attacker injects a message;
- **Interception** or *eavesdropping*: an attacker reads a message.

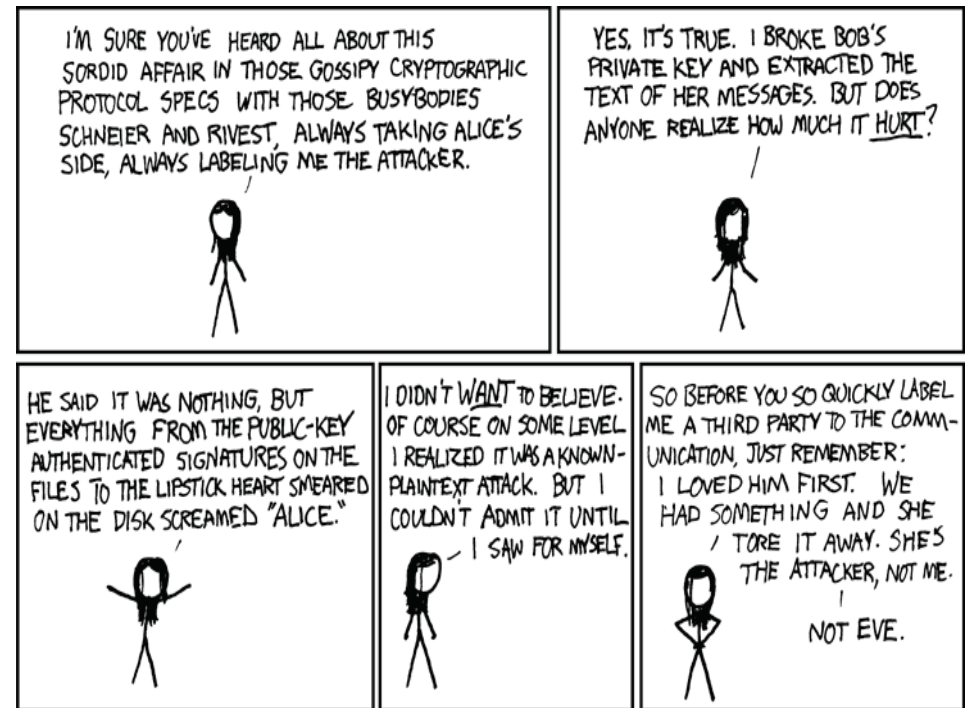


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Darkside security (Thomborson)

- One person's functional goal is another person's security threat – and vice versa.
- Stallman's attack model is appropriate for Alice, in her traditional role in an analysis of communication security.
 - Alice is talking to Bob.
 - Eve is trying to eavesdrop: she poses a threat to the confidentiality of Alice's conversation.
 - Mallory is trying to modify messages, posing a threat to the integrity of Alice's conversation.
 - See http://en.wikipedia.org/wiki/Alice_and_Bob for some other standard characters.
- Let's consider Eve's point of view...

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Source: <http://xkcd.com/177/>, reproduced with permission (<http://xkcd.com/license.html>).

Evading Walter

- If Alice is a prisoner, she cannot communicate with Bob unless she has permission from Walter (her warden).
 - Stegocommunication threat: Alice might find a surreptitious way to communicate with Bob.
- Have you ever wondered about the stegomessages which might be sent, without your knowledge, by your computer?
 - Using open-source code can mitigate this threat...
 - Do you trust the person who compiled the code you are using?
 - Do you trust the people who wrote the compiler?
<http://doi.acm.org/10.1145/358198.358210>

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Evading Mallory

- If Alice doesn't have a right to integrity in her messaging...
 - Threat: Alice might add error-correcting codes to her messages, which would allow Bob to “undo” Mallory's modifications.
- Many of your documents have metadata which could reveal information you would not want to reveal.
 - Many lawyers have learned, the hard way, never to send contractual offers in MS Word format.
 - How can you be confident that Alice (your word-processing software, or your OS) won't actually preserve some information you “delete” from a document or a filesystem?

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Evading Daniel

- What if Alice doesn't have a right to availability in her messaging?
 - Threat: Alice might find a way to evade Daniel, whose goal is to deny service.
- If your computer or browser (Alice) is taken over by malware, will you be able to shut off its communications?
 - You can easily unplug a wired-Ether connection... but can you shut down all of the comm channels on your cellphone or PDA?
 - What can you do if your computer or cellphone doesn't respond to its “off” switch?

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Evading Fabian

- What if Bob doesn't have the right to know that it was actually Alice who sent the message signed “Alice”?
 - Threat: Alice might find a way to sign her messages so that Fabian (a fabricator) can not fool Bob.
- I don't have a white-hat scenario for this threat... can you think of one?
- The point I'm trying to make in these last few slides is that “Security” is not a well-defined property, until you assign roles to participants and decide who is wearing a “white-hat”!

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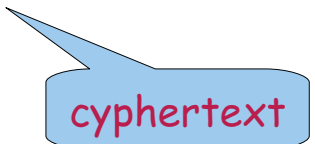
Back to CIA...

- Most networks are designed for the “CIA” goals:
 - Security goal #1: confidentiality for Alice & Bob
 - Security goal #2: integrity for Alice & Bob
 - Security goal #3: availability for Alice & Bob
- It seems to be infeasible to achieve all three goals.
- In the usual design for a “secure communication system”,
 - availability is compromised, and
 - Alice and Bob gain (partial) confidentiality with encryption. Eve can tell that Alice & Bob are sending messages to each other, but she can't understand what the messages mean.

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Encryption = coding with a secret

- Coding schemes are designed to be decoded by an algorithm that is widely known.
- Encryption schemes are codes which need special knowledge to decode them.
- **Xibu jt uijt tjnqmf fodsqujpo?**



cyphertext

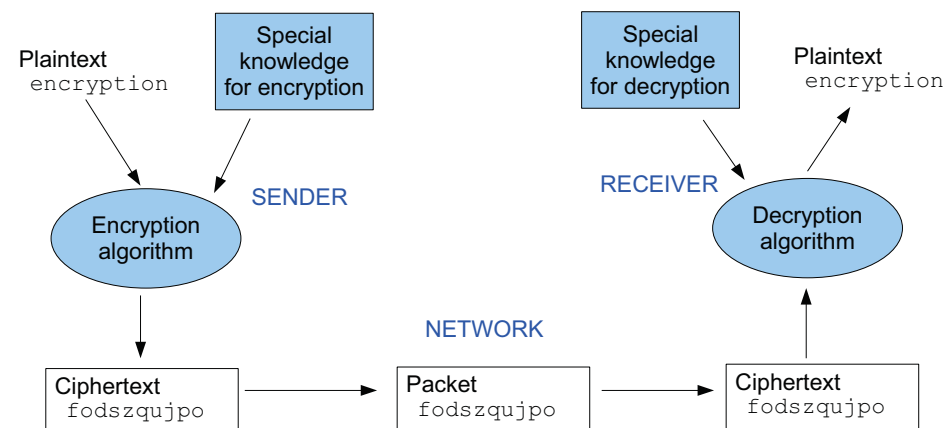
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Types of Secrets...

- The decoding algorithm might be a secret.
 - “Security by obscurity”: a bad idea (unless it's your only option)
- A generally-known algorithm might require a secret input: the decoding “key”.
- **Xibu jt uijt tjnqmf fodszaqujpo?**
- **What is this simple encryption?**
 - The algorithm is “go back N letters”
 - The special knowledge is “N=1”

plaintext
or cleartext

Encryption and decryption



Without the special knowledge (key), an intruder on the network cannot understand the packet, and cannot change it or insert a new one without being detected.

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Terminology

- Call the plaintext (the message) P
- The encryption algorithm is E
 - Its special knowledge is a key k
 - The ciphertext $C = E_k(P)$
- The decryption algorithm is D
 - Its special knowledge is a key k'
 - The plaintext $P = D_{k'}(C)$
 - By definition, $P = D_{k'}(E_k(P))$

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The Caesar code

- Probably the oldest cryptographic algorithm
- E is: go forward N letters in the alphabet, rotating from Z to A.
 - k is N
- D is: go back N letters in the alphabet, rotating from A to Z.
 - k' is N
- When $k = k'$ we speak of a *symmetric-key* algorithm or a *shared key*. Both ends must know the same secret key.

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What makes a good cryptographic algorithm?

- Assuming it's widely used, there's no point in trying to keep the algorithms E and D secret.
 - Disclosing E and D can be beneficial. See Tomlinson (1853) and Kerckhoffs (1887).
 - But you must keep your key secret!
- A cryptographic system is called “strong” if experts believe no one will crack an encoded message within the next 20 years – not even using millions of computers trying all possible keys.
 - Is the Caesar code strong?

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How big should the key be?

- Obviously this depends on the exact E and D algorithms, but assume that the attacker has a few supercomputers.
- Let's assume (s)he can check one million keys per second.
- That's 31,536,000,000,000 keys per year.
- To be reasonably safe for 1000 years, you certainly need a pool of 31,536,000,000,000,000 keys to choose from.
- That's almost 2^{55} (a 55 bit binary number).
- Modern cryptography goes further than that, as we'll see.

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Example: original DES* (1977)

- Divide message into 64 bit blocks of plaintext
- Encrypt each block with a 56 bit key
 - The encryption process includes 18 major steps, including transposition of bit strings and XOR between parts of the message and parts of the key
 - The output is a 64 bit block of ciphertext

0	0	0
0	1	1
1	0	1
1	1	0

The truth table for exclusive-or (XOR)

* DES = Data Encryption Standard

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Why DES uses XOR

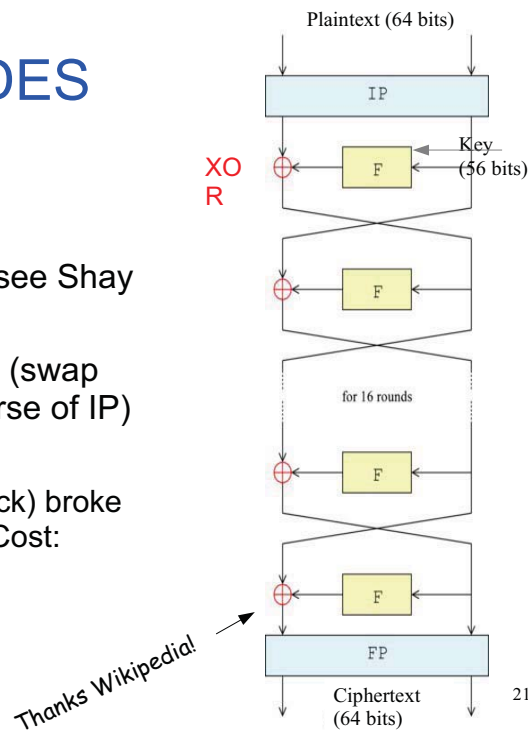
- Note that XOR is in itself a simple symmetric cryptographic algorithm

$P=110011, k=010101 \rightarrow C=XOR(110011,010101)=100110$
 $C=100110, k=010101 \rightarrow P=XOR(100110,010101)=110011$
- What DES does is build on this property using multiple cycles and transpositions to make the result more pseudo-random
- Hard to crack without knowing the 56 bit key.
 - Is 56 bits enough?

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Overview of DES

- IP = Initial Permutation (transposition)
- F = "Feistel" function (see Shay p. 289 for more details)
- FP = Final Permutation (swap and transposition, reverse of IP)
- In July 1998, the EFF's DES cracker (Deep Crack) broke a DES key in 56 hours. Cost: \$250,000.



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Block vs. Stream Ciphers

- DES is a block cipher – it produces 64-bit blocks of cipher text from 64-bit blocks of cleartext.
 - If Alice encrypts the same cleartext M under the same key k , she'll get the same ciphertext $E_k(M)$.
- Alice must change keys more often than she sends the same cleartext block.
 - Otherwise she'll reveal information about her "repeated blocks" to Eve. (See the next slide.)
- Alice wants to send long messages without worrying about repeats and key-changes.
 - She really wants a stream cipher, not a block cipher.

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Cryptanalysis: Repeated Blocks

- If we DES-encode all 64-bit blocks of a picture (in bitmap format) under the same key...



http://en.wikipedia.org/wiki/Block_cipher_modes_of_operation,
<http://www.isc.tamu.edu/~lewing/linux/>

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A Quick-and-Dirty Stream Cipher

- CBC = Cipher Block Chaining
 - Before each 64-bit plaintext block P_n is encrypted, XOR it with the previous cyphertext block C_{n-1}
 - Repeated blocks are now very rare, so the trivial pattern-matching attack of the previous slide is ineffective.
 - A clever attacker can still guess a pattern of repeats...
- Alice should not repeat herself, if she's using a CBC cipherstream and is worried about a clever Eve.
 - Alice should compress her cleartext before encrypting it.

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Triple DES

- Basically, apply DES three times running, so that $C = E_{k3}(D_{k2}(E_{k1}(P)))$
- where E is DES encryption and D is DES decryption
 - if $k1=k2=k3$ this is single DES for backwards compatibility
- Triple DES is still regarded as reasonably safe, but is slow, especially in software-only implementations.

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Advanced Encryption Standard (AES)

- Preferred to Triple DES due to longer keys and greater complexity
 - Also has better software performance
- 128 bit block cipher with 128, 192 or 256 bit keys
- Mathematically complex
 - like DES, involves transposition steps and XOR, but also includes substitution tables in each round
 - currently regarded as safe for all practical purposes

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Problems with symmetric keys

- Both ends must know the same key
 - Doubles the risk of leaks
 - Can't determine who leaked the key
- Initialisation problem: How can Alice send a key safely to Bob without encrypting it?
 - In practice: use an existing secure channel (post?, telephone?), monitor the first few uses of a new key, use Diffie-Hellman key-exchange, ...
- If I want secure links to 100,000 customers, then I have to manage 100,000 keys!

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Asymmetric keys

- Suppose I could decrypt using k' and tell all my customers to encrypt using k .
- If I keep k' secret, nobody else can decrypt messages that were encrypted using k .
- So if I receive a message encrypted with k saying "Today's AES key is 11011....011101", only I can decrypt it, and the AES key is safe.
- In this case k is my public key (everybody knows it) and k' is my private key (nobody else knows it).

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RSA* algorithm

- Choose two large prime numbers p and q
 - Let $n = pq$
 - Let $n' = (p-1) \times (q-1)$
- Find k which has no common factors with n' .
 k will be the encryption (public) key.
- Find k' such that $(kk'-1)$ is an exact multiple of n' .
 k' will be the decryption (private) key.
- Encryption consists of raising each block of the plaintext to the power k , modulo n .
- Decryption consists of raising each block of the cyphertext to the power k' , modulo n .

* Rivest, Shamir and Adleman

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Magic?

- RSA is based on number theory and seems like magic, but it works. Go through the example in Shay, or look at the excellent Wikipedia entry.

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Two ways to use RSA keys

1. Alice uses Bob's public key to encrypt a message to Bob; only Bob can decrypt it.
 - But anybody could pretend to be Alice!
2. Alice uses her private key to encrypt a hash of her message; Bob uses Alice's public key to decrypt and check the hash value.
 - Only Alice can perform this encryption, so the encrypted hash is a digital signature.
 - If the hash matches, Bob knows that Alice sent the message and nobody changed it.
 - More magic: in fact, Alice uses RSA decryption to "encrypt" the hash, and vice versa.

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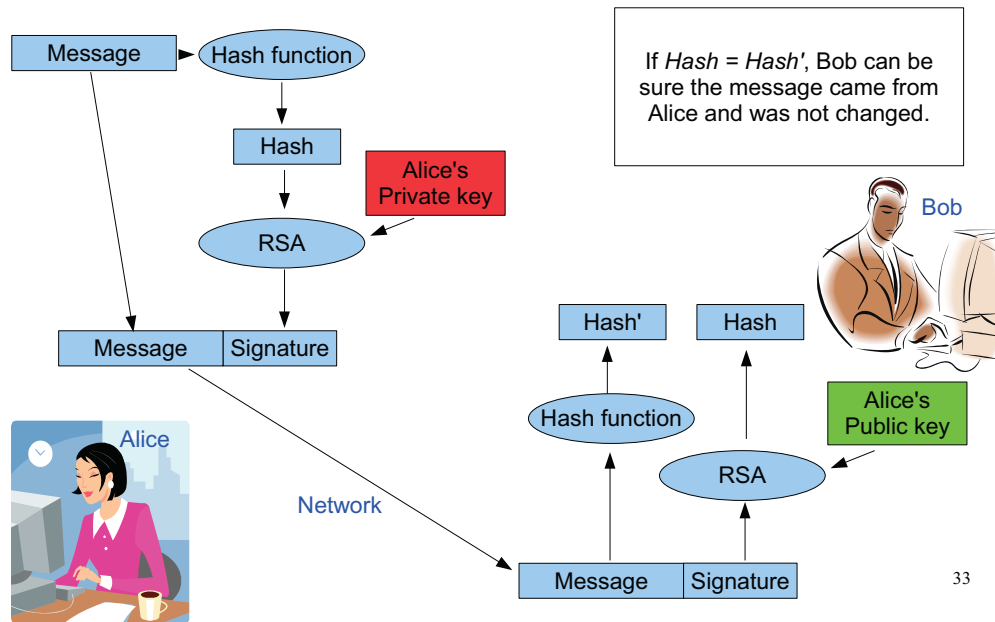
Cryptographic Hash Functions

- These are functions somewhat like a checksum or CRC, but designed for cryptographic use.
 - Input is any length of message, and output is a fixed length hash value (at least 128 bits).
- Its mathematical design is not aimed at bit error detection, like a normal CRC, but at resistance to attack or detection of forgery.
 - In particular it should be very hard to create a fraudulent message that has the same hash as the genuine message
 - SHA-256 and SHA-512 are commonly used, and still seem secure, but are nearing the end of their useful life.

<http://csrc.nist.gov/groups/ST/hash/sha-3/Round2>

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Signing a message: overview



Who are Alice and Bob anyway?

- In many analyses of security algorithms, Alice and Bob are the two parties trying to communicate securely, and often Eve is the person trying to listen in or interfere
 - Apologies to anyone called Alice, Bob or Eve...



Alice



Eve



Bob

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What problems do Alice and Bob face?

- At the start, they can trust nothing - any message could be forged or read by Eve. They have to assume that:
 - Eve can see all their packets.
 - Eve can store packets and play them back later.
 - Eve can send her own packets with forged IP addresses.
 - Eve has a lot of computing power.

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The importance of authentication

- We could spend the whole semester on security, but will focus on authentication.
- “Source authentication” (that a message was sent by a given source, and not tampered with) is the key to preventing most types of attack:
 - detects modification and spoofing of messages
 - prevents repudiation of genuine messages
 - helps detection of floods of invalid messages
 - helps to secure the sending of encryption keys across an initially insecure channel

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How to authenticate that Bob is Bob

- We assume that Eve is trying to pretend to be Bob.
- A message that merely says "I'm Bob" proves nothing... and might be suspicious! (Would Bob really send such a message?)
- A message signed with Bob's private key, that Alice can check with Bob's public key, is OK.
- But a message saying "Hi, I'm Bob and here's my public key", signed with the corresponding private key, isn't OK. Why not?

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Who do you trust?

- If *www.BobsWebSite.org* lists Bob's public key, are you willing to believe it?
- If yes:
 - How do you know that Eve didn't create that web site?
 - How do you know that Eve didn't hack that web site, even if it's one that Bob created?
 - Are you sure you aren't looking at *www.BobsWebSite.org*?
- Really, you can only trust a public key from a highly reputable source. (But... how do you identify a reputable source??!)

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Trust and Trustworthiness

- Security analysts distinguish “trust” from “trustworthiness”.
- If Alice believes that she has a valid copy of Bob's public key, then she “trusts” this key whenever she relies on it (i.e. to verify a message from Bob).
- If Alice actually has Bob's public key, then her reliance on the validity of this key is appropriate – we say this key is “trustworthy”.

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What can Alice do with a trusted public key for Bob?

- Check that it really is Bob who's sending messages to her and that they are unchanged (since Eve cannot forge Bob's RSA signature).
- Prove later, to herself, and to anyone else who trusts this key, that Bob really did send a message (since Alice cannot forge Bob's RSA signature).
- Send a secure message to Bob providing a symmetric key for AES encryption (since Eve cannot read a message encrypted with Bob's public key).
- Efficiently discard any flood of bogus messages from Daniel (since Daniel cannot forge anybody else's RSA signature)

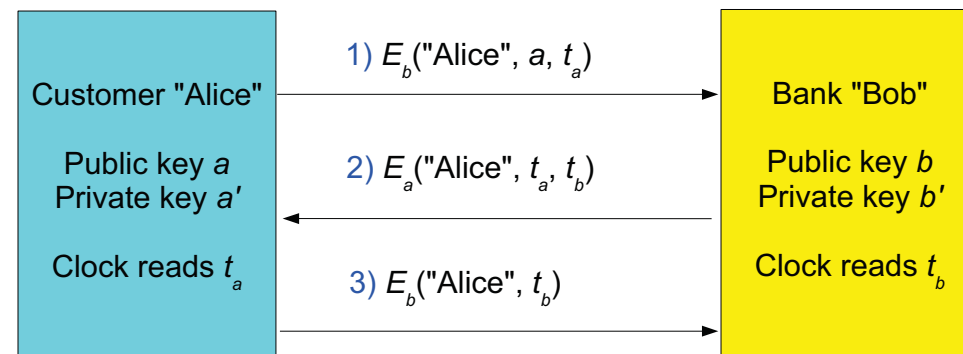
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A simple authentication protocol

- *Problem:* Convince a bank called Bob that you really are a customer called Alice.
- *Notation:*
 - E is RSA encryption
 - D is RSA decryption
 - a, a' are Alice's public and private keys
 - b, b' are Bob's public and private keys
 - thus $E_a(P)$ is plaintext P encrypted with Alice's public key, etc.
 - t_a, t_b are clock times on Alice's and Bob's clocks

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Does this work?



- 1) Alice provides her key and timestamp
- 2) Bob confirms timestamp and adds his own
- 3) Alice confirms Bob's timestamp

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What did Bob and Alice learn?

- Bob knows that "Alice" knew his public key
- Bob knows a public key for "Alice"
- Bob knows that "Alice" received his timestamp
- Alice knows that Bob knows her public key
- Alice knows that Bob received her timestamp
- Eve couldn't decipher the messages, but could store them
- *Has Alice proved her identity to Bob's server? (Authentication)*
- *Is Alice allowed to use Bob's service? (Authorization)*
- *Can Eve use a copy of message 3 to gain service? (Eavesdrop, then Replay; or Intercept, then Inject)*
- *What is the value of the timestamps?*

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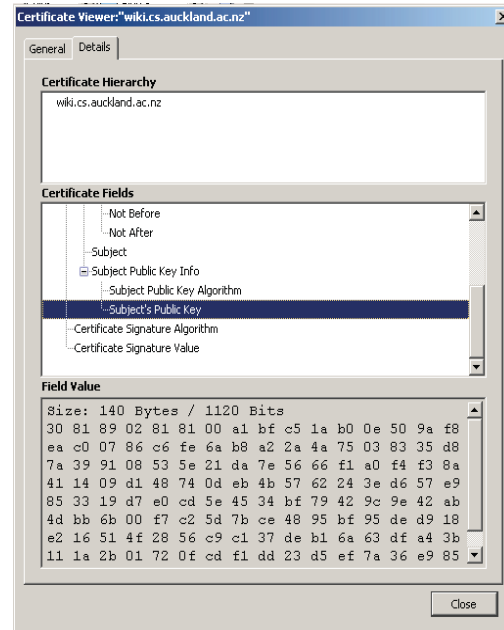
Authentication pitfalls

- How does Alice know she's talking to the genuine Bob?
 - This needs a source of trust for Bob's public key, typically an X.509 certificate
- How does Alice convince Bob she's the genuine Alice?
 - Typically this needs a reliable shared secret. The simplest kind is a pre-arranged password sent over an encrypted channel (e.g. encrypted with Bob's public key).

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X.509 certificate

- This is a document that is cryptographically signed by a trusted third party known as a CA (Certification Authority).
- Apart from the signature and administrative material, it contains the public key.
- ("X.509" identifies a particular international standard.)



Trust is recursive

- Instead of trusting Bob's web site, Alice now has to trust Bob's CA.
- Web browsers have the public keys for reputable CAs built into them.
- Now Alice has to trust the web browser.
- So she has to trust the download site where the web browser came from.
- Which means trusting the download site's CA.
- Trust is not easy...

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Summary on encryption and authentication

- We've seen how symmetric and asymmetric encryption systems work.
- They can be used to create secure channels and to check message authenticity.
- They can be used to build authentication protocols, but only based on some prior knowledge (a public key) and on some trusted third party.
- We'll see specific examples (TLS and SSH) later.

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