Cryptography

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The role of cryptography in O/S

- Core questions we've encountered:
  - I claim to be "Ken Birman". But can I prove this?
  - The web site claims to be "M&T Bank.com". But is it?
  - You make a purchase from Amazon.com and need to enter your credit card information. Can spies see it?
  - You and your friend are exchanging some very sensitive email. Can it be kept secret from third parties?
- On a single machine, O/S provides protection using user/group IDs, permissions, and by ensuring that distinct processes have distinct address spaces

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Early days

- Earliest uses of cryptography were to implement login
  - Systems like UNIX maintained a password file
    - Anyone could read it… but the passwords were in an encrypted form
  - When you logged in, they would compute the encryption of your password and see if it matched the file version
  - If so, allowed you to log in…

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Early days

- But then people realized that brute force tools could often find passwords
  - First reaction was to hide the password file more carefully
  - Leads to a focus on network security, because more and more the passwords are in a secured machine out on the network!

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Hardware

- These days most computers include "trusted platform modules" or TPMs
  - Special hardware
  - It has a built-in key (we'll see what kind soon)
  - Effectively, the TPM can say "Dell.com vouches for this machine, it's name is Ken'sLaptop"
- TPM can do some simple cryptographic operations
  - If widely adopted would result in much better security
  - But in fact not widely used today

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The role of cryptography in O/S

- We tend to turn to cryptographic techniques in networked settings where there are multiple machines
- Several questions arise
  - First, what "tools" can cryptography give us?
  - Then, how can we embed these tools into the network in convenient, safe, secure ways?
  - Finally, what sorts of limitations are we left with?

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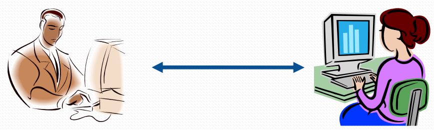
Basic setup

- We'll think in terms of situations where there are two processes that need to communicate
  - Call them Sally and Ted
- Let's start by exploring ways that Sally and Ted can share secrets



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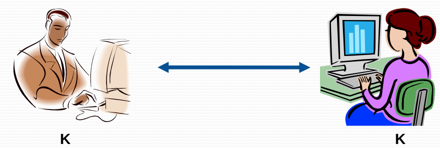
Symmetric cryptography

- In this approach, Sally starts by creating a secret key and sharing it (somehow) in a secure way with Ted
- They both have the identical key.
- Then we can define some functions in terms of the key



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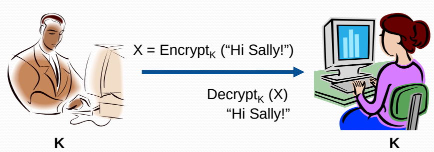
Symmetric crytography

- $Encrypt_K$ (m): encrypts message m using key K
- $Decrypt_K$ (m): decrypts message m using key K
- $Sign_K$ (m): computes a *signature* for message m
  - This is a short (usually 128 bit) number that is calculated from m and then encrypted with K
  - Uses to detect tampering, or as proof that "Sally saw m"



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On the Internet

- Encrypted messages look like random bits!
  - An intruder can't make any sense out of them at all
  - A good encryption scheme should have the property that even if you *know* what the message really says, you can't figure out the key without trying every possible key
- Goal: create a problem that is computationally infeasible today... and will stay that way tomorrow!

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Symmetric cryptography

- There are many popular implementations of this kind of cryptographic system
  - For example, US government recommends something called DES, the Digital Encryption Standard
  - For some purposes DES isn't secure enough, but if you create *three* keys and apply DES three times, result is very robust ("triple DES")
  - For signatures, many systems compute an "MD5 hash" and then encrypt it
- Of course, Sally and Ted still have the problem of creating that initial shared key in a secure way!

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Asymmetric cryptography

- Also called "public key" cryptography
- A clever scheme that eliminates need to share the key initially
  - In practice a bit slow, so sometimes we start with asymmetric keys and then "exchange" them for symmetric ones
  - This would be one way for our symmetric keys to get shared between Sally and Ted....

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Asymmetric cryptography

- Basic idea:
- Sally picks a public key K and a private key K^{-1}
- There is a well known known function *crypt* s.t.:
  - $crypt_{K^{-1}}$ ($crypt_K$ (m)) = m
  - $crypt_K$ ($crypt_{K^{-1}}$ (m)) = m
- She publishes her public key K_{sally}
- Ted does exactly the same thing, using his own keys

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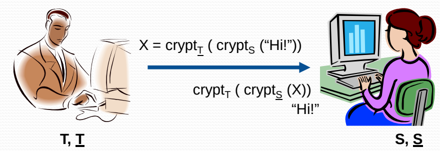
Asymmetric cryptography

- Let's use S for Sally's public key and S̲ for her private key
- Similarly, T and T̲ for Ted's key pair
- For Ted to send a secret message m to Sally:
  - Ted computes X = $crypt_{\underline{T}}$ ($crypt_S$ (m))
  - Sally computes M = $crypt_T$ ($crypt_{\underline{S}}$ (X))
- Only Ted could have sent this. Only Sally can read it!



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RSA implementation?

- Basic idea:
- Sally selects two very big prime numbers *p* and *q*
- She computes
  1. A <u>modulus</u> $n = p*q$
  2. A <u>totient</u> $\varphi(n) = (p-1)*(q-1)$
  3. She picks an integer *e* such that $1 < e < \varphi(n)$, s.t. *e* and $\varphi(n)$ are coprime (share no divisor other than 1)
  4. She calculates *d* s.t. $d*e == 1 \bmod \varphi(n)$
- Sally releases her public key as *(e, n)*. She retains *d* as her private key.

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RSA implementation?

- Sally publishes her public key (e,n) to Ted
- To compute $crypt_S$ (m):
  - Bob transforms m into a big integer 0 < M < n (using a standard "padding" scheme)
  - Now he computes X = M^e *mod* n
  - X is the encrypted text (in this case, encrypted with Sally's public key)
- To decrypt, Sally needs to compute $crypt_{\underline{S}}$ (X)
  - M = X^d *mod* n

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Notes

- Notice that encrypt and decrypt are really the same computation but using different keys
  - X = M^e *mod* n, to encrypt
  - M = X^d *mod* n, to decrypt
- Why does it work?
  - encrypt(decrypt(M)) = M^{e*d} *mod* n

    Theorem (Gauss):

    If $d*e == 1 \bmod \varphi(n)$ then (M^{e*d} *mod* n) = (M^1 *mod* n) = M
  - … hence encrypt(decrypt(M)) = M ***qed***

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Notes

- Notice also that encrypt and decrypt can be applied in any order, even with multiple keys
  - This is quite useful
  - For example, makes it possible to ask a service to "sign" something that it can't actually look at, much like a notary public in a bank
    - First I encrypt the object with my public key
    - Then send it to the notary, who encrypts with her private key
    - Then I decrypt with my private key… and end up with a "notarized" object (specifically, encrypted with the notary's private key, and decryptable with her public key)
    - Yet she never saw the object she notarized!

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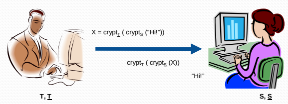
Using asymmetric keys

- Ted can send a message that only Sally can read
  - Just encrypt it with her public key first
- Ted can send a message that only he can have sent
  - Just encrypt it with his private key first
- Or both.....



- An encrypted hash is often used as a signature

Pros and Cons

- With asymmetric keys one party can easily send things to the other party
  - We do need a way to publish the public information… but this turns out to be reasonably easy
- But these keys are slow (bignum arithmetic…)
  - So a common trick is for Ted to send Sally a proposed symmetric (shared and private) key
  - Once Sally accepts it, she and Ted switch to using that key, with symmetric cryptography, which is ***very*** fast

How to share public keys?

- There is an Internet standard for so-called "certificate repositories"
  - A certificate is a signed record that contains cryptographic information, like Sally's public key
  - Who signs it? The "certificate authority"
- These are built as hierarchies, like the DNS

Trusted Platform Module

- This is one answer to the question… Remember the TPM?
  - What it contains is a private key (burned into hardware)
  - Public key can be obtained from Dell.com
- This lets us imagine software that "can only be executed on Ken's Laptop" or "an image that Sophie's Pentax Optio D-60 took in New Orleans at this GPS coordinate on Thursday May 11, 2003…"
  - But as mentioned, not widely used

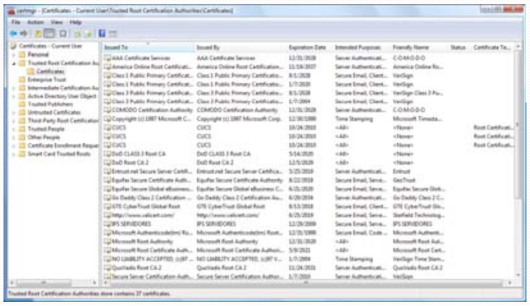
A Public Key Infrastructure (PKI)

- Your O/S has a root key built in
  - That root "signs" for top-level CA such as Verisign
  - Amazon.com registers their certificate with Verisign
- So when you want to talk to Amazon.com… it tells you to get its certificate from Verisign
- Microsoft says you can trust Verisign… and Verisign gives you the Amazon certificate

What's in a certificate?

- Name of the entity the key is for
- Type of key (RSA in our examples)
- Expiration time
- Signature of the CA vouching for the certificate

Windows Certificate Manager



How does HTTPS work?

- HTTPS runs over a form of secured TCP
  - This TCP layer is called the Secure Socket Layer or SSL
  - Transport Layer Security, or TLS, has started to replace it
- TLS involves three basic phases:
  - Peer negotiation for **algorithm support**
  - Key exchange and authentication
  - Symmetric cipher encryption and message authentication

Negotiation Step

- The two end points agree on the cryptographic protocol suite they will use
  - For example, RSA, Diffie-Hellman, etc
  - Idea is to be flexible enough so that a bank, or the military, could use a scheme of its own

Key exchange step

- This works very much as in our examples
  - One peer selects a session key and creates a small certificate for it
    - Includes things like the key, the expiration time, a random number, the identity of the sender
    - Designed to prevent man-in-the-middle or replay attacks
  - Then uses PKI to obtain initial keys
  - Then securely send the certificate for the session key
- Outcome: TCP endpoints have key material and have agreed on the encryption algorithm they are using

Symmetric encryption/authentication

- Once the keys are in place, each message sent on the secured TCP connection is
  - Encrypted, to keep the bytes secret
  - Authenticated, to prevent injection of garbage, replay of old messages, etc
- If correctly implemented, end-points can be confident that spies and attackers can't disrupt their communication

Common worries about PKIs

- There are actually no widely adopted standards for Ted to talk to Sally!
  - The standard lets Ted talk to Google via gmail
  - And it lets Sally talk to Google
  - But what if Ted and Sally don't trust Google?
- The entire model focuses on trusted vendors
  - Entities who can pay Verisign for certificates…
  - This makes sense for buying products on web sites
  - The right model for things like group collaboration (e.g in a medical setting) doesn't really exist yet!

Single Sign-On

- A popular refinement
  - Issue: Ted ends up with accounts at 10 different places
  - He wants to sign on once as Ted and have the single sign-on work at all of those accounts
- For example: "MSN Live Passport"
- Idea of Single Sign On is that there can be a company that holds your keys for various sites
  - You log into it once (the single sign-on)
  - And it releases certificates you can use at those sites

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So, how good is web security?

- Pretty bad, actually
  - The cryptographic part works fairly well
  - But all the stuff "surrounding" it has weaknesses
- Many machines are vulnerable to viruses that attack with simple things (like buffer overruns) or by exploiting known configuration weaknesses
  - Like standard preset passwords and passwords that are way too easy to guess
  - Some applications can even be tricked into running commands for an intruder! For example via automated patch install scripts…

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So, how good is web security?

- More issues
  - Web browsers have many security issues
  - Reflects a tension between wanting browser to be powerful (like able to attach files to email) and wanting it to be secured
- Overwhelming commercial pressures around advertising placement don't help at all
  - Motivates companies to send you "adware" (== malware that isn't exactly malicious but definitely isn't desired!)
  - In-flight modifications of web pages, bad web proxies, other tricks and gotcha's more and more common…

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