Cryptographic Keys
CS 136
Computer Security
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Outline

- Properties of keys
- Key management
- Key servers
- Certificates

Introduction

- It doesn’t matter how strong your encryption algorithm is
- Or how secure your protocol is
- If the opponents can get hold of your keys, your security is gone
- Proper use of keys is crucial to security in computing systems

Properties of Keys

- Length
- Randomness
- Lifetime
- Secrecy

Key Length

- If your cryptographic algorithm is otherwise perfect, its strength depends on key length
- Since the only attack is a brute force attempt to discover the key
- The longer the key, the more brute force required

Are There Real Costs for Key Length?

- Generally, more bits is more secure
- Why not a whole lot of key bits, then?
- Some encryption done in hardware
  - More bits in hardware costs more
- Some software encryption slows down as you add more bits, too
  - Public key cryptography especially
- Some algorithms have defined key lengths only
- If the attack isn't brute force, key length might not help

Key Randomness

- Brute force attacks assume you chose your key at random
- If attacker learns how you chose your key
  - He can reduce brute force costs
- How good is your random number generator?

Generating Random Keys

- Well, don't use `rand()`[1]
- The closer the method chosen approaches true randomness, the better
- But, generally, don't want to rely on exotic hardware
- True randomness is not essential
  - Need same statistical properties
  - And non-reproducibility

[1]See http://eprint.iacr.org/2013/338.pdf for details

Cryptographic Methods

- Start with a random number
- Use a cryptographic hash on it
- If the cryptographic hash is a good one, the new number looks pretty random
- Produce new keys by hashing old ones
- Depends on strength of hash algorithm
- Falls apart if any key is ever broken
  - Doesn’t have *perfect forward secrecy*

Perfect Forward Secrecy

- A highly desirable property in a cryptosystem
- It means that the compromise of any one session key will not compromise any other
  - E.g., don’t derive one key from another using a repeatable algorithm
- Keys do get divulged, so minimize the resulting damage

Random Noise

- Observe an event that is likely to be random
  - Physical processes (cosmic rays, etc.)
  - Real world processes (variations in disk drive delay, keystroke delays, etc.)
- Assign bit values to possible outcomes
- Record or generate them as needed
- More formally described as *gathering entropy*
- Keys derived with proper use of randomness have good perfect forward secrecy

On Users and Randomness

- Some crypto packages require users to provide entropy
  - To bootstrap key generation or other uses of randomness
- Users do this badly (often very badly)
- They usually try to do something simple
  - And not really random
- Better to have crypto package get its own entropy

Don’t Go Crazy on Randomness

- Make sure it’s non-reproducible
  - So attackers can’t play it back
- Make sure there aren’t obvious patterns
- Attacking truly unknown patterns in fairly random numbers is extremely challenging
  - They’ll probably mug you, instead

Key Lifetime

- If a good key's so hard to find,
  - Why every change it?
- How long should one keep using a given key?

Why Change Keys?

- Long-lived keys more likely to be compromised
- The longer a key lives, the more data is exposed if it's compromised
- The longer a key lives, the more resources opponents can (and will) devote to breaking it
- The more a key is used, the easier the cryptanalysis on it
- **A secret that cannot be readily changed should be regarded as a vulnerability**

Practicalities of Key Lifetimes

- In some cases, changing keys is inconvenient
  - E.g., encryption of data files
- Keys used for specific communications sessions should be changed often
  - E.g., new key for each phone call
- Keys used for key distribution can't be changed too often

Destroying Old Keys

- Never keep a key around longer than necessary
  - Gives opponents more opportunities
- Destroy keys securely
  - For computers, remember that information may be in multiple places
    - Caches, virtual memory pages, freed file blocks, stack frames, etc.
  - Real modern attacks based on finding old keys in unlikely places

Key Storage

- The flip side of destroying keys –
  – You'd better be sure you don't lose a key while you still need it
- Without the key, you can't read the encrypted data
  – Kind of a bummer, if you wanted to
- Key storage is one approach

What Is Key Storage?

- Saving a copy of a cryptographic key "somewhere else"
- Securely store a key in some safe place
- If you lose it accidentally, get it back from storage location
- Prevents encrypted data from becoming unreadable

Where Should You Store Keys?

- Must not be accessible to an attacker
  - Don't want him to get hold of all your keys
  - Don't want them readily available if your machine is hacked
- But relatively accessible when needed
- Usually on a separate machine

How Do You Get Keys There?

- And back
- Each new key must be transported to the key server
- Not much saved if transport mechanism is compromised
- Need carefully designed/implemented mechanism for moving keys

Key Secrecy

- Seems obvious
- Of course you keep your keys secret
- However, not always handled well in the real world
- Particularly with public key cryptography

Some Problems With Key Sharing

- Private keys are often shared
  - Same private key used on multiple machines
  - For multiple users
  - Stored in "convenient" places
  - Perhaps backed up on tapes in plaintext form

Why Do People Do This?

- For convenience
- To share expensive certificates
- Because they aren't thinking clearly
- Because they don't know any better
- A recent example:
  - RuggedCom's Rugged Operating System for power plant control systems
  - Private key embedded in executable

To Make It Clear,

- **PRIVATE KEYS ARE PRIVATE!**
- They are for use by a single user
- They should never be shared or given away
- They must never be left lying around in insecure places
  - Widely distributed executables are insecure
  - Just because it’s tedious to decipher executables doesn’t mean can’t be done
- The entire security of PK systems depends on the secrecy of the private key!

Key Management

- Choosing long, random keys doesn’t do you any good if your clerk is selling them for $10 a pop at the back door
- Or if you keep a plaintext list of them on a computer on the net whose root password is “root”
- Proper key management is crucial

Desirable Properties in a Key Management System

- Secure
- Fast
- Low overhead for users
- Scaleable
- Adaptable
  - Encryption algorithms
  - Applications
  - Key lengths

Users and Keys

- Where are a user's keys kept?
- Permanently on the user's machine?
  – What happens if the machine is cracked?
- But people can't remember random(ish) keys
  – Hash keys from passwords/passphrases?
- Keep keys on smart cards?
- Get them from key servers?

Key Servers

- Special machines whose task is to generate, store and manage keys
- Generally for many parties
- Possibly Internet-wide
- Obviously, key servers are highly trusted

Security of Key Servers

- The key server is the cracker's holy grail
  - If they break the key server, everything else goes with it
- What can you do to protect it?

Security for Key Servers

- Don't run anything else on the machine
- Use extraordinary care in setting it up and administering it
- Watch it carefully
- Use a key server that stores as few keys permanently as possible
  - At odds with need for key storage
- Use a key server that handles revocation and security problems well

Single Machine Key Servers

- Typically integrated into the web browser
  - Often called *key chains* or *password vaults*
- Stores single user's keys or passwords for various web sites
- Usually protected with an overall access key
- Obvious, encrypted versions stored on local disk

Security Issues for Single Machine Key Servers

- Don’t consider one that doesn’t store keys encrypted
- Issues of single sign-on
  – If computer left unattended
  – In case of remote hacking
    - Anything done by your web browser is “you”

Local Key Servers

- Can run your own key server machine
  - Stores copies of all keys you use
- Possibly creates keys when needed
- Uses careful methods to communicate with machines using it
- E.g., Oracle Key Manager 3
  - Primarily intended for tapes

Key Storage Services

- Third party stores your keys for you
  - In encrypted form they can't read
- ANSI standard (X9.24) describes how third party services should work
- Not generally popular
- HyperSafe Remote Key System is one example
- Variants may become important for cloud computing

Certificates

- A ubiquitous form of authentication
- Generally used with public key cryptography
- A signed electronic document proving you are who you claim to be
- Often used to help distribute other keys

Public Key Certificates

- The most common kind of certificate
- Addresses the biggest challenge in widespread use of public keys
  - How do I know whose key it is?
- Essentially, a copy of your public key signed by a trusted authority
- Presentation of the certificate alone serves as authentication of your public key

Implementation of Public Key Certificates

- Set up a universally trusted authority
- Every user presents his public key to the authority
- The authority returns a certificate
  - Containing the user's public key signed by the authority's private key
- In essence, a special type of key server

Checking a Certificate

- Every user keeps a copy of the authority's public key
- When a new user wants to talk to you, he gives you his certificate
- Decrypt the certificate using the authority's public key
- You now have an authenticated public key for the new user
- Authority need not be checked on-line

Scaling Issues of Certificates

- If there are 1-2 billion Internet users needing certificates, can one authority serve them all?
- Probably not
- So you need multiple authorities
- Does that mean everyone needs to store the public keys of all authorities?

Certification Hierarchies

- Arrange certification authorities hierarchically
- Single authority at the top produces certificates for the next layer down
- And so on, recursively

Using Certificates From Hierarchies

- I get a new certificate
- I don’t know the signing authority
- But the certificate also contains that authority’s certificate
- Perhaps I know the authority who signed this authority’s certificate

Extracting the Authentication

- Using the public key of the higher level authority,
  - Extract the public key of the signing authority from the certificate
- Now I know his public key, and it's authenticated
- I can now extract the user's key and authenticate it

A Example

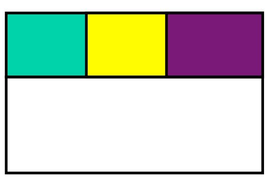
Alice gets a message with a certificate

Then she uses
to check

Should Alice believe that he's really ?

So she uses
to check

Give me a certificate saying that I'm



Alice has never heard of
But she has heard of

How can prove who he is?

Certification Hierarchies Reality

- Not really what's used
  - For the most part
- Instead, we rely on large numbers of independent certifying authorities
  - Exception is that each of them may have internal hierarchy
- Essentially, a big list
- Is this really better?

Certificates and Trust

- Ultimately, the point of a certificate is to determine if something is trusted
  - Do I trust the request enough to perform some financial transaction?
- So, Trustysign.com signed this certificate
- How much confidence should I have in the certificate?

Potential Problems in the Certification Process

- What measures did Trustysign.com use before issuing the certificate?
- Is the certificate itself still valid?
- Is Trustysign.com's signature/ certificate still valid?
- Who is trustworthy enough to be at the top of the hierarchy?

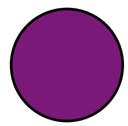
Trustworthiness of Certificate Authority

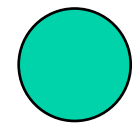
- How did Trustysign.com issue the certificate?
- Did it get an in-person sworn affidavit from the certificate's owner?
- Did it phone up the owner to verify it was him?
- Did it just accept the word of the requestor that he was who he claimed to be?
- Has authority been compromised?

What Does a Certificate Really Tell Me?

- That the certificate authority (CA) tied a public/private key pair to identification information
- Generally doesn’t tell me why the CA thought the binding was proper
- I may have different standards than that CA

Showing a Problem Using the Example

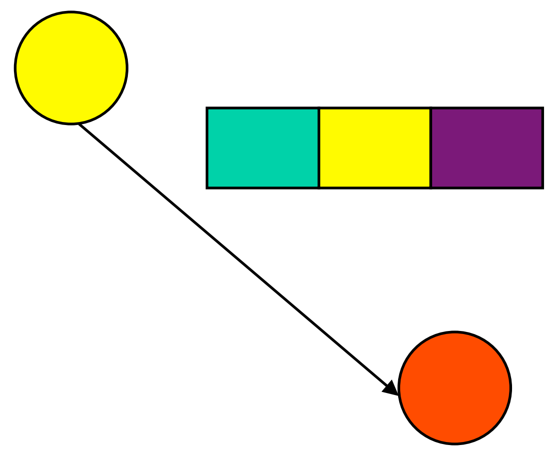


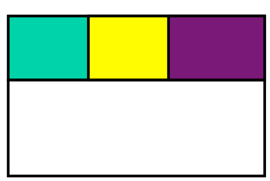


What if uses 's lax policies to pretend to be ?

Alice likes how verifies identity

But is she equally happy with how verifies identity?





Does she even know how verifies identity?

Another Big Problem

- Things change
  - E.g., recent compromise of Adobe private keys
- One result of change is that what used to be safe or trusted isn't any more
- If there is trust-related information out in the network, what will happen when things change?

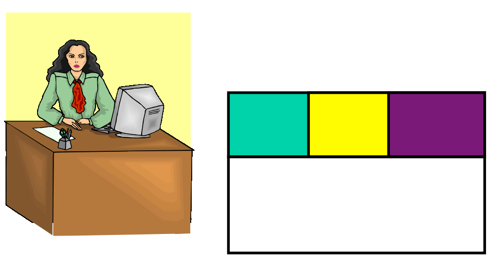
Revocation

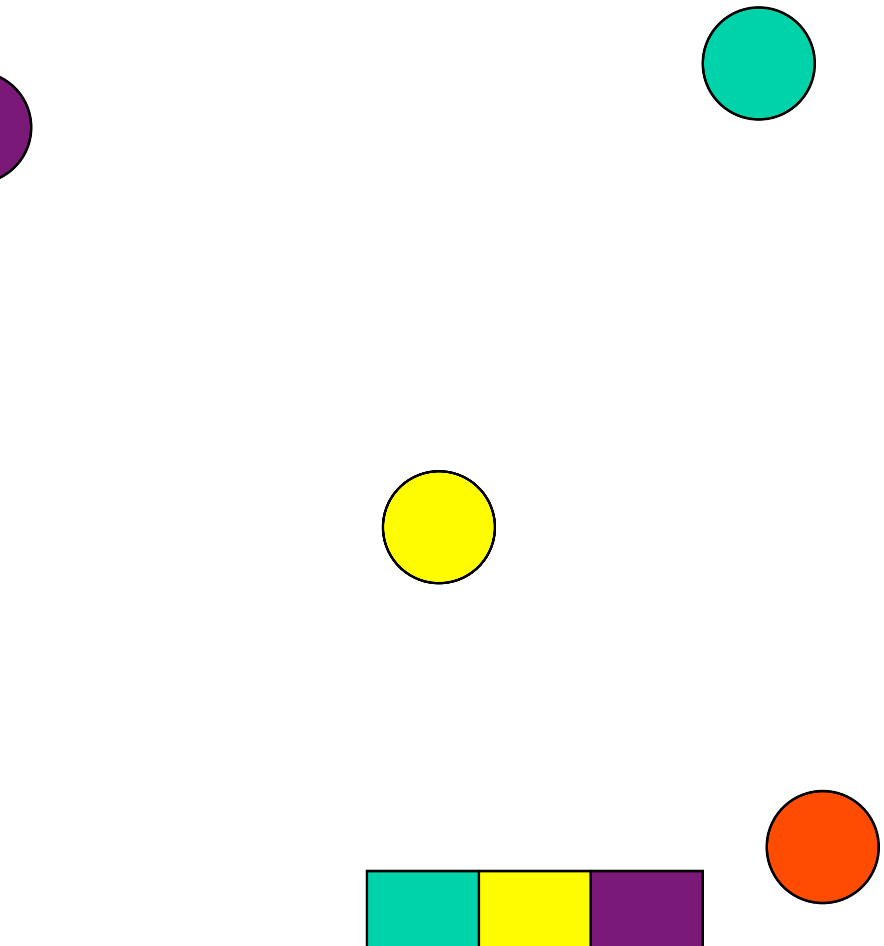
- A general problem for keys, certificates, access control lists, etc.
- How does the system revoke something related to trust?
- In a network environment
- Safely, efficiently, etc.
- Related to revocation problem for capabilities

Revisiting Our Example

Someone discovers that has obtained a false certificate for

How does Alice make sure that she's not accepting 's false certificate?





Realities of Certificates

- Most OSes come with set of "pre-trusted" certificate authorities
- System automatically processes (i.e., trusts) certificates they sign
- Usually no hierarchy
- If not signed by one of these, present it to the user
  - Who always accepts it . . .

An Example

- Firefox web browser
- Makes extensive use of certificates to validate entities
  – As do all web browsers
- Comes preconfigured with several certificate authorities
  – Over 200 of them

Firefox Preconfigured Certificate Authorities

- Some you'd expect:
  - Microsoft, RSA Security, Verisign, etc.
- Some you've probably never heard of:
  - Unizeto Sp. z.o.o., Netlock Halozatbiztonsagi Kft.,Chungwa Telecom Co. Ltd.

The Upshot

- If Netlock Halozatbiztonsagi Kft. says someone's OK, I trust them
  – I've never heard of Netlock Halozatbiztonsagi Kft.
  – I have no reason to trust Netlock Halozatbiztonsagi Kft.
  – But my system's security depends on them

The Problem in the Real World

- In 2011, a Dutch authority (DigiNotar) was compromised
- Attackers generated lots of bogus certificates signed by DigiNotar
  - "Properly" signed by that authority
  - For popular web sites
- Until compromise discovered, everyone trusted them

Effects of DigiNotar Compromise

- Attackers could transparently redirect users to fake sites
  - What looked like Twitter was actually attacker's copycat site
- Allowed attackers to eavesdrop without any hint to users
- Apparently used by authorities in Iran to eavesdrop on dissidents

How Did the Compromise Occur?

- DigiNotar had crappy security
  - Out-of date antivirus software
  - Poor software patching
  - Weak passwords
  - No auditing of logs
  - Poorly designed local network
- A company providing security services paid little attention to security

But how were you supposed to know that?

A Firefox Solution

- Certificate key pinning
- Code into the browser the "right" signing authority for particular sites
- So a certificate for Google signed by, say, DigiNotar gets rejected
- Currently only for a couple of big name web sites

Another Practicality

- Certificates have expiration dates
  - Important for security
  - Otherwise, long-gone entities would still be trusted
- But perfectly good certificates also expire
  - Then what?

The Reality of Expired Certificates

- When I hear my server's certificate has expired, what do I do?
  - I trust it anyway
  - After all, it's my server
- But pretty much everyone does that
  - For pretty much every certificate
- Not so secure

The Core Problem With Certificates

- Anyone can create some certificate
- Typical users have no good basis for determining whose certificates to trust
  - They don’t even really understand what they mean
- Therefore, they trust almost any certificate

Should We Worry About Certificate Validity?

- Starting to be a problem
  – Stuxnet is one example
  – Compromise of DigiNotar and Adobe also
  – Increasing incidence of improper issuance, like Verisign handing out Microsoft certificates
- Not the way most attackers break in today
- With all their problems, still not the weakest link
  – But now being exploited, mostly by most sophisticated adversaries

Heartbleed and Certificates

- OpenSSL relies on certificates and private keys for key distribution
- If Heartbleed compromised those, then serious problems
  - Just like DigiNotar, but for all certificate authorities at once
- Current evidence suggests Heartbleed can expose certificates
  - No evidence it ever did, but . . .
  - So we may need to change all certificates

Should I Trust Crypto At All?

- Recent revelations suggest that the NSA can read many encrypted messages
- Experts think they mostly have compromised key selection/handling
  - Rather than the crypto itself
- But also possible that particular implementations have been "bugged"

Some Practical Advice on Crypto

- From Bruce Schneier, who should know
- **Use crypto to protect your data**
- **Trust the math, not the program**
- **Be suspicious of commercial crypto**
  - **Especially from big companies**
- **Use public-domain crypto whenever possible**
  - **Especially standards requiring interoperability**