Class 36: Public Key Crypto

CS150: Computer Science
University of Virginia
Computer Science

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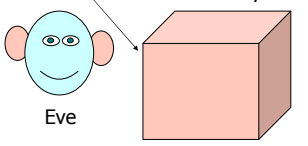
Login Process

Terminal

```
Login: alyssa
Password: fido
```

login sends
<"alyssa", "fido">



Password Problems

- Need to store the passwords
  - Dangerous to rely on database being secure

Lecture 31, Recap Now

- Need to transmit password from user to host
  - Dangerous to rely on Internet being confidential

Today

Hashed Passwords

UserID	Password
alyssa	f("fido")
ben	f("schemer")
dave	f("Lx.Ly.x")

Dictionary Attacks

- Try a list of common passwords
  - All 1-4 letter words
  - List of common (dog) names
  - Words from dictionary
  - Phone numbers, license plates
  - All of the above in reverse
- Simple dictionary attacks retrieve most user-selected passwords
- Precompute $\mathrm{H}(x)$ for all dictionary entries

(at least) 86% of users are dumb and dumber

Single ASCII character	0.5%
Two characters	2%
Three characters	14%
Four alphabetic letters	14%
Five same-case letters	21%
Six lowercase letters	18%
Words in dictionaries or names	15%
Other (possibly good passwords)	**14%**

(Morris/Thompson 79)

Salt of the Earth

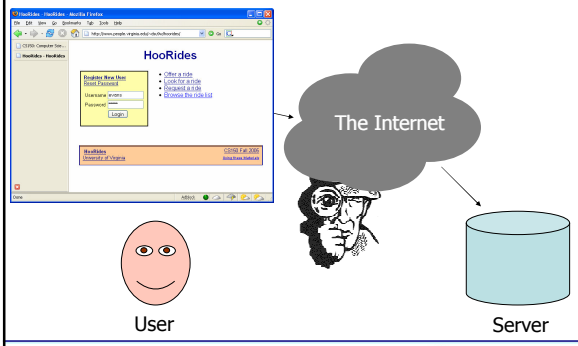
Salt: 12 random bits

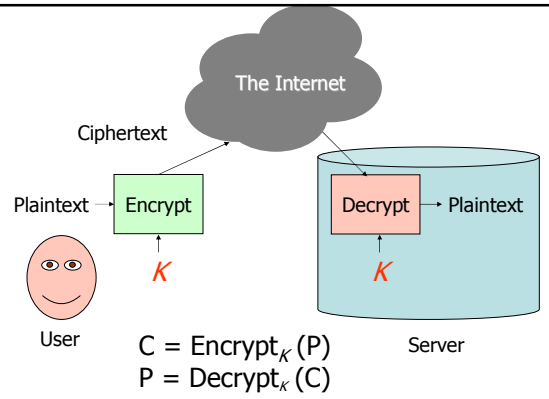
UserID	Salt	Password
alyssa	1125	crypt ("Lx.Ly.x", 1125)
ben	2437	crypt ("schemer", 2437)
dave	932	crypt ("Lx.Ly.x", 932)

How much harder is the off-line dictionary attack?

In HooRides.net we use the user name as the salt. Is this better or worse?

Sending Passwords

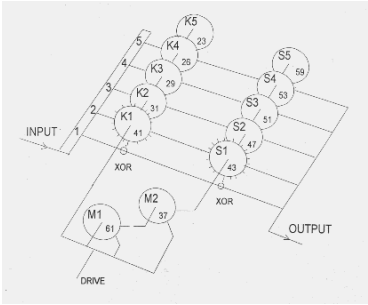




$C = Encrypt_K(P)$

$P = Decrypt_K(C)$

PS4: Lorenz Cipher



From http://www.codesandciphers.org.uk/lorenz/fish.htm

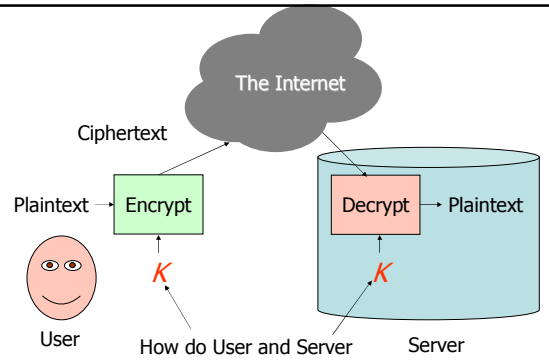
Modern Symmetric Ciphers

A billion billion is a large number, but it's not that large a number. Whitfield Diffie

- Same idea but:
  - Use digital logic instead of mechanical rotors
  - Larger keys (random bits, not rotor alignments)
    - PS4 = 5^3; Lorenz ≈ 5^{12} < 10^9
    - Modern ≥ 128 bits > 10^{37}
  - Encrypt blocks of letters at a time

Modern Ciphers

- AES (Rijndael) successor to DES selected 2001
- 128-bit keys, encrypt 128-bit blocks
- Brute force attack (around 10^{30} times harder than Lorenz)
  - Try 1 Trillion keys per second
  - Would take 10790283070806000000 years to try all keys!
  - If that's not enough, can use 256-bit key
- No known techniques that do better than brute force search



Key Agreement Demo

(Animated version at end of slides.)

Asymmetric Cryptosystems

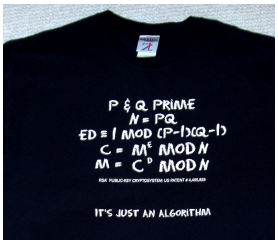
- Need a hard problem (like symmetric cryptosystems)
- With a trap door: if you know a secret, the hard problem becomes easy

One-Way Functions

- Easy to compute, hard to invert
- Trap-door one way function:
  - $D(E(M)) = M$
  - E and D are easy to compute.
  - Revealing E doesn't reveal an easy way to compute D.
  - Hence, anyone who knows E can encrypt, but only someone who knows D can decrypt

RSA [Rivest, Shamir, Adelman 78]

One-way function:
multiplication is easy, factoring is hard
Trap-door: number theory (Euler and Fermat)



Security of RSA

- n is public, but not p and q where $n = pq$
- How much work is factoring n?

  Number Field Sieve (fastest known factoring algorithm) is:

$$O(e^{1.9223((\ln(n))^{1/3}(\ln(\ln(n)))^{2/3})})$$

n ~200 digits – would take quintillions of years

The movie Sneakers is about what happens if someone discovers a $O(n^k)$ factoring algorithm.

Asymmetric Cryptosystems

- Encryption and Decryption are done with different keys
- Keep one of the keys secret, reveal the other

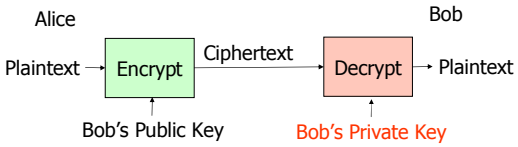
$$E_{KRA}(E_{KUA}(M)) = M$$

Alice's Public Key: KUA

Alice's Private Key: KRA

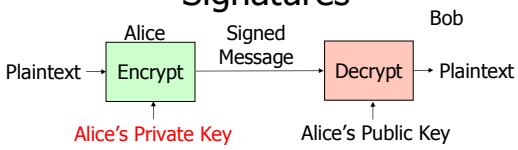
Only KRA can decrypt a message encrypted using KUA.

Public-Key Applications: Privacy

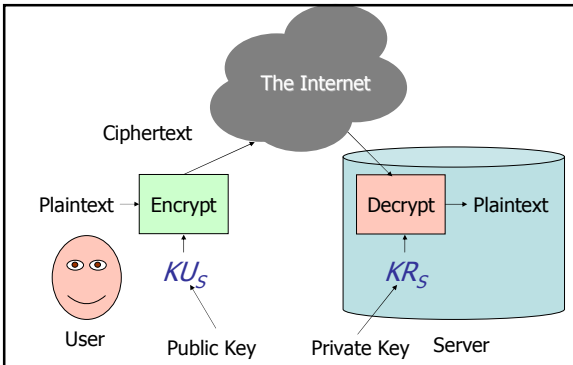


- Alice encrypts message to Bob using Bob's Private Key
- Only Bob knows Bob's Private Key ⇒ only Bob can decrypt message

Signatures



- Bob knows it was from Alice, since only Alice knows Alice's Private Key
- Non-repudiation: Alice can't deny signing message (except by claiming her key was stolen!)
- Integrity: Bob can't change message (doesn't know Alice's Private Key)



How does User know the public key to use?

Key Management

Approach 1: Meet Secretly

- User and Server Operator meet secretly and swap public keys
  - If you can do that, might as well agree on a secret (symmetric key) instead
  - Doesn't work for Internet transactions

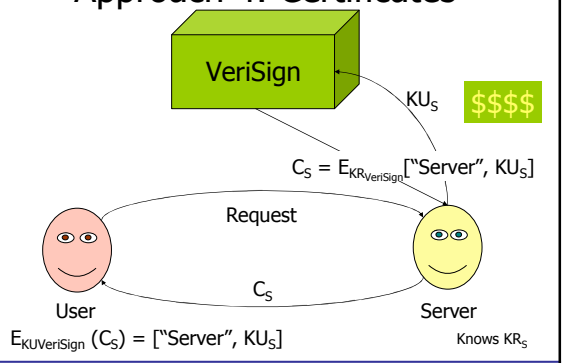
Approach 2: Public Announcement

- Publish public keys in a public forum
  - Append to email messages
  - Post on web site
  - New York Time classifieds
- Easy for rogue to pretend to be someone else
  - Forge email, alter web site, lie to New York Times

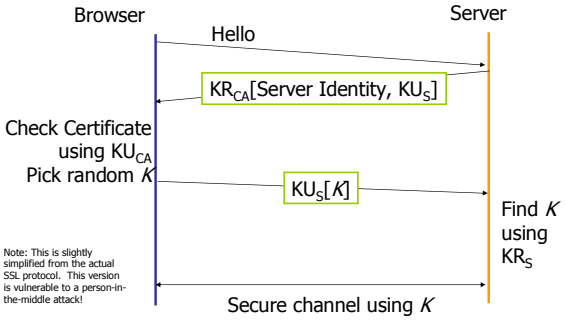
Approach 3: Public Directory

- Trusted authority maintains directory mapping names to public keys
- Entities register public keys with authority in some secure way
- Authority publishes directory
  - Print using watermarked paper, special fonts, etc.
  - Allow *secure* electronic access
    - Depends on secure distribution of directory's key

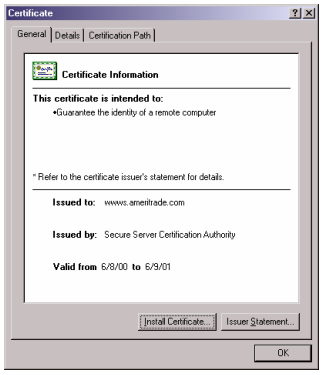
Approach 4: Certificates

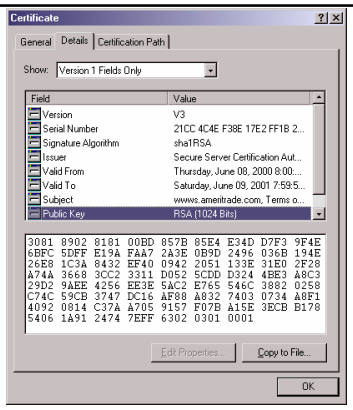


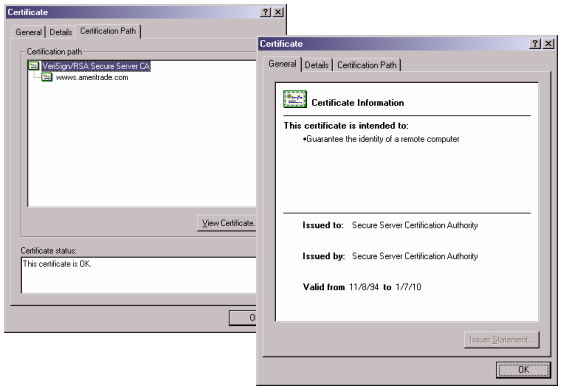
SSL (Secure Sockets Layer)



Data encrypted using secret key exchanged using some public key associated with some certificate.







How do you make your web site password form encrypt its input?

http:// ⇒ https://

Exam 2: Requested Topics

Topic	Average		
Biology (Monday's class)	4.130435		
Finding Aliens	4.347826	10	3
How Google Works	2.695652	17	11
Hardware			
Implementing Interpreter	7.217391	1	0
Software Security	6.434783	1	0
Languages & Complexity	7.565217	3	1
Testing	6.409091	2	0
Viruses and Worms	4.78		
Complex Language	5.68		

Friday's class will be on this (as well as on finding prime factors)

The 2 classes after Thanksgiving will be about Google

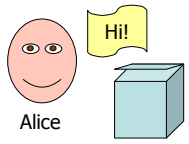
Manuvir Das' talk today at 3:30 (Olsson 009) will include these topics (how Microsoft makes software more reliably)

Charge

- Project Meetings today, tomorrow and Friday

Animated version of Asymmetric Cryptography Demo

Padlocked Boxes



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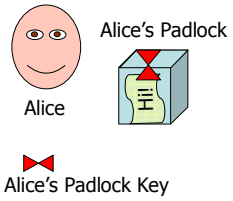

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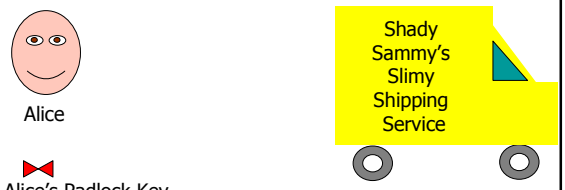

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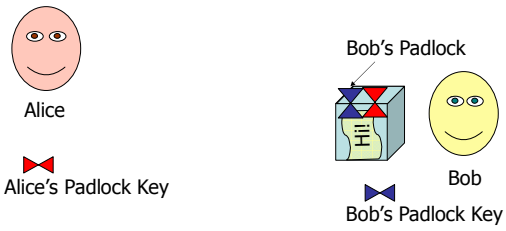

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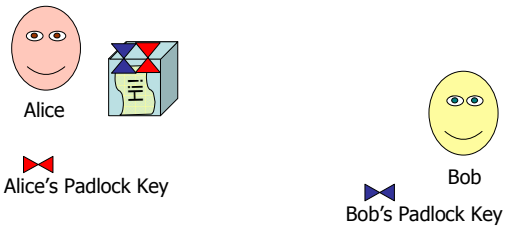

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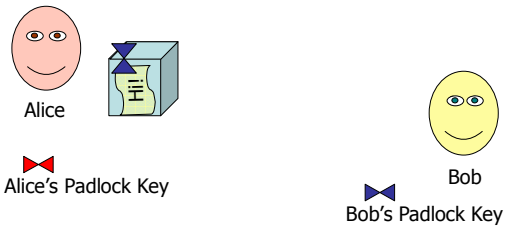

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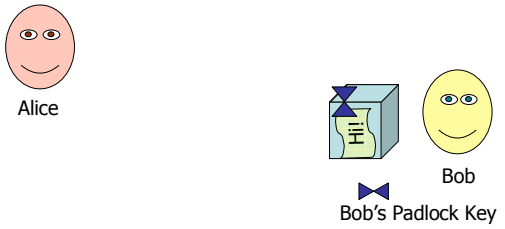

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