Class 4: Modern Cryptography

http://www.cs.virginia.edu/jillcrypto

Menu

- Some loose ends on WWII
- Maurice Burnett
- Modern Cryptography
  - Modern symmetric ciphers
  - Public-key cryptosystems

British Cipher Machine

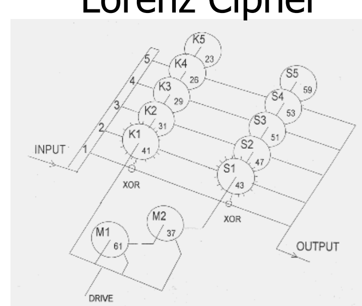
- Design based on commercial Enigma
- 5 rotor wheels (instead of 3 in Enigma)
- Multiple rings per rotor
- Last 2 rotor wheels didn't rotate
- British attempted to break it (without success)

Typex Machine

German Code-Breaking Efforts

- About 6,000 people (compare to 12,000 working at Bletchley Park)
- Decentralized: each military branch had their own, didn't share what they learned
- Effective against manual codes: broke about 50% of manually coded messages
- Didn't attempt to break rotor-based ciphers – so confident Enigma was unbreakable, didn't try to Typex and similar machines

Lorenz Cipher



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

Modern Symmetric Ciphers

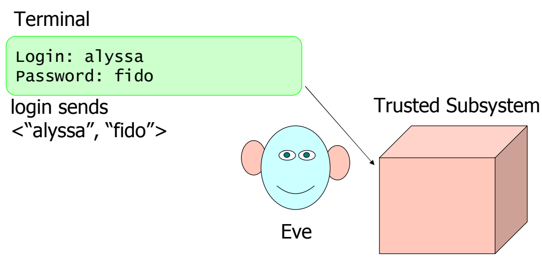
A billion billion is a large number, but it's not that large a number.
Whitfield Diffie

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

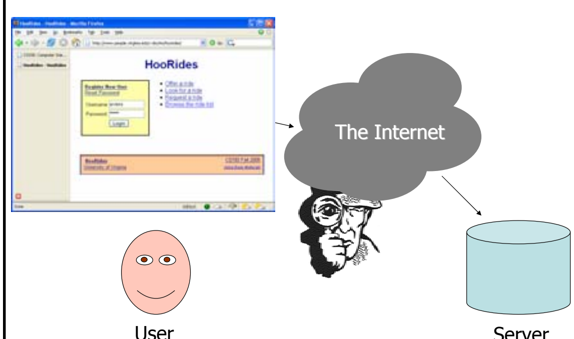
Modern Ciphers

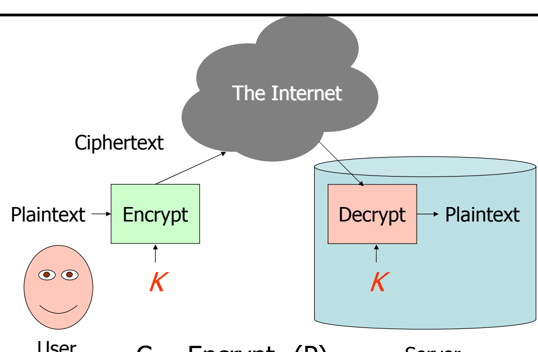
- AES (Rijndael) successor to DES selected 2001
- 128-bit keys, encrypt 128-bit blocks
- Brute force attack (around 10^{30} times harder than Lorenz)
  - Try 1 Trillion keys per second
  - Would take 10790283070806000000 years to try all keys!
  - If that's not enough, can use 256-bit key
- No known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

Login Process



Sending Passwords





$C = \text{Encrypt}_K(P)$
$P = \text{Decrypt}_K(C)$

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

Asymmetric Cryptosystems

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

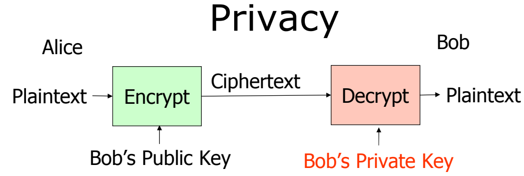
$$E_{KRA}(E_{KUA}(M)) = M$$

Alice's Public Key: KUA

Alice's Private Key: KRA

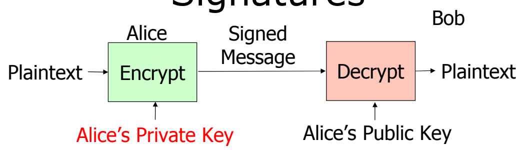
Only KRA can decrypt a message encrypted using KUA.

Public-Key Applications: Privacy

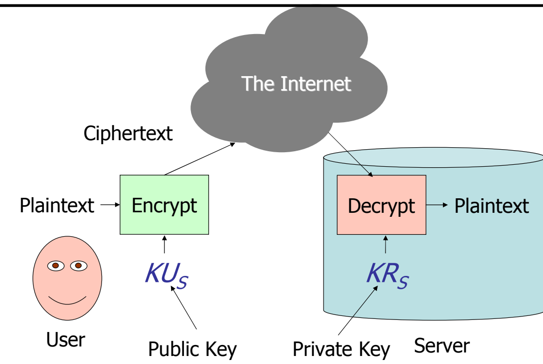


- Alice encrypts message to Bob using Bob's *Public* Key
- Only Bob knows Bob's *Private* Key ⇒ only Bob can decrypt message

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

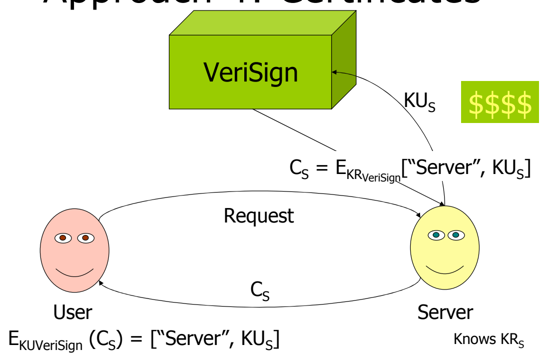
Approach 2: Public Announcement

- 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

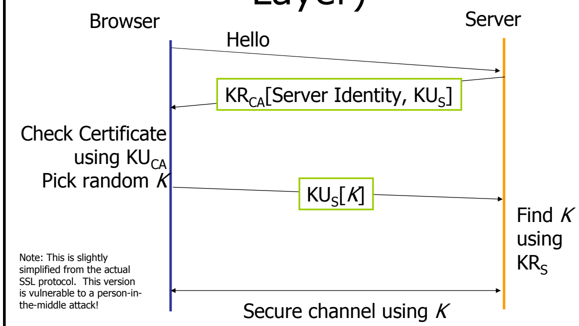
Approach 3: Public Directory

- 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

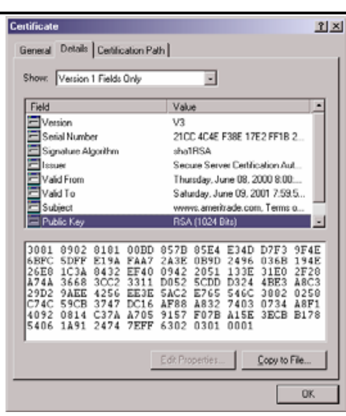
Approach 4: Certificates

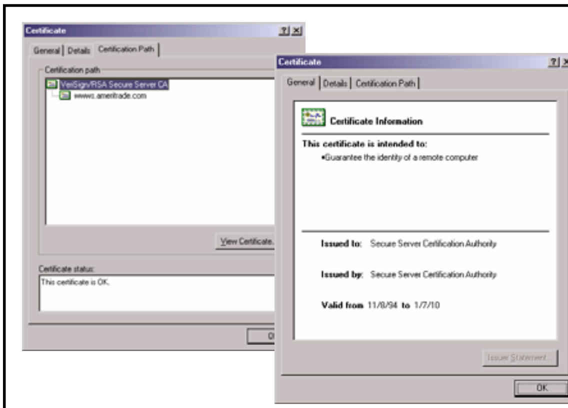


SSL (Secure Sockets Layer)

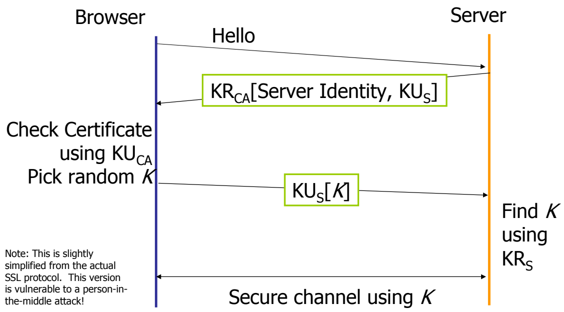


Data encrypted using secret key exchanged using some public key associated with some certificate.





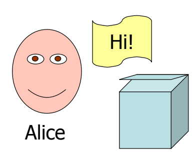
SSL Recap



Questions?

Animated version of Asymmetric Cryptography Demo

Padlocked Boxes



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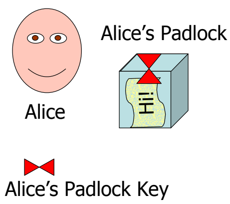

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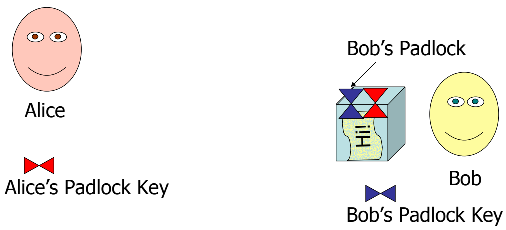

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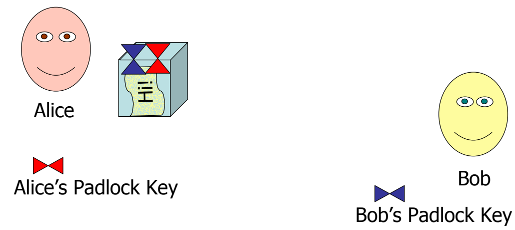

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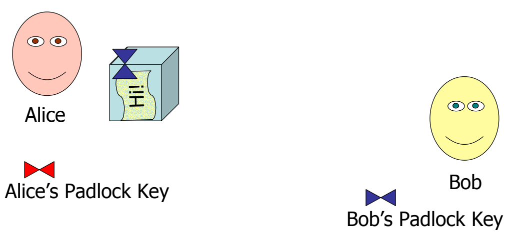

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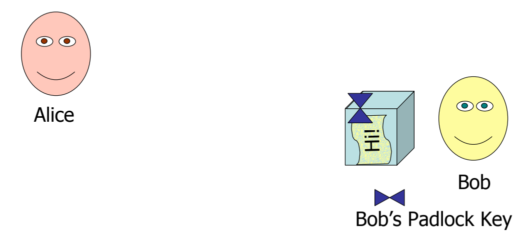

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