Cryptography:

Gur Cbjre bs Xabjyrqtr

15-441, Lecture 5
Wolf Richter

Announcements

- HW1 deadline extended to 9/20
- Project 1 Checkpoint 1 this Friday
- Repos: [4:12PM 9/12/11] 21/59 = 35.5%

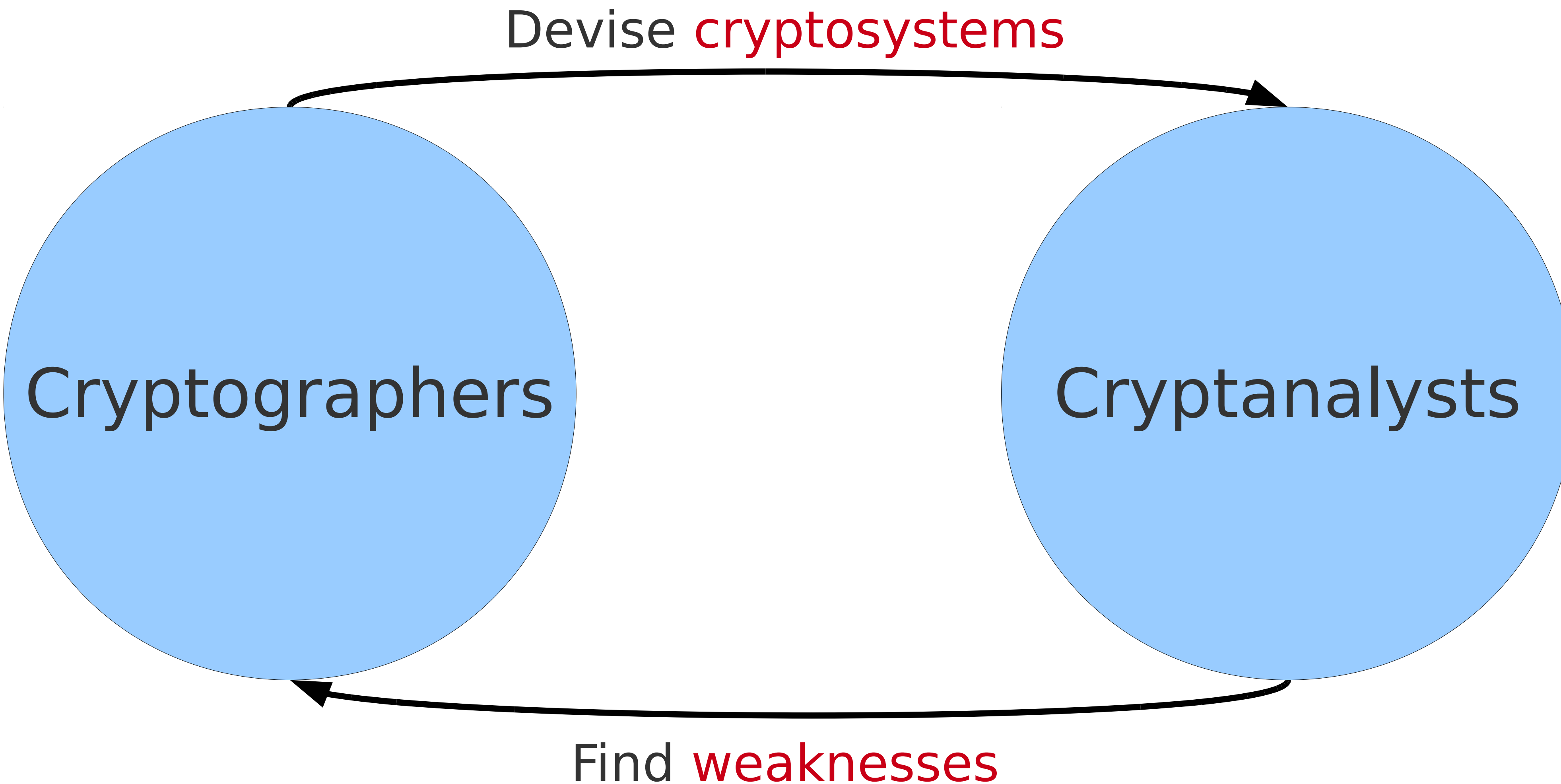
What will we learn today?

- Why: brief history
- How: Cryptography and Steganography
  - Codes
  - Ciphers
    - Symmetric, Asymmetric
- Today: Kerberos, HTTPS

A continuous arms race

- 1000's of years of guarding secrets
- Spartans – scytale, transposition cipher
- Romans – Caesar Cipher, rotation cipher
- Allied Analysis broke the ADFGVX
    - Led to the Zimmerman Letter decryption
    - Led to US involvement in WWI
- Breaking ENIGMA during WWII
    - Led to Allied tactical advantages

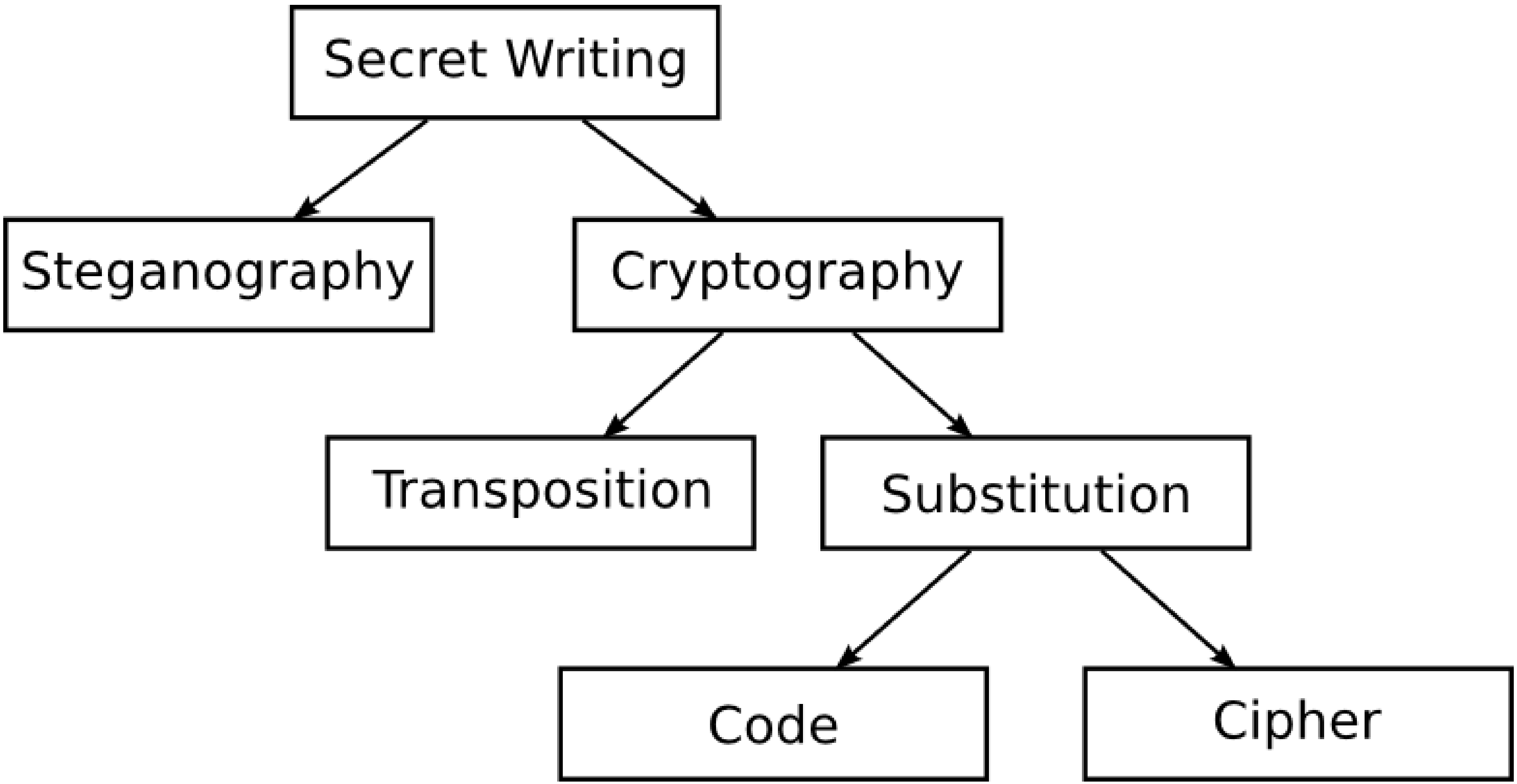
A continuous arms race



Desired properties [Schneier96]

- Confidentiality – Ensure that an eavesdropper can not read a message.
- Authentication – It should be possible for the receiver of a message to ascertain its origin; an intruder should not be able to masquerade as someone else.
- Integrity – It should be possible for the receiver of a message to verify that it has not been modified in transit; an intruder should not be able to substitute a false message for a legitimate one.
- Nonrepudiation – A sender should not be able to falsely deny later that he sent a message.

The history of communication



Steganography

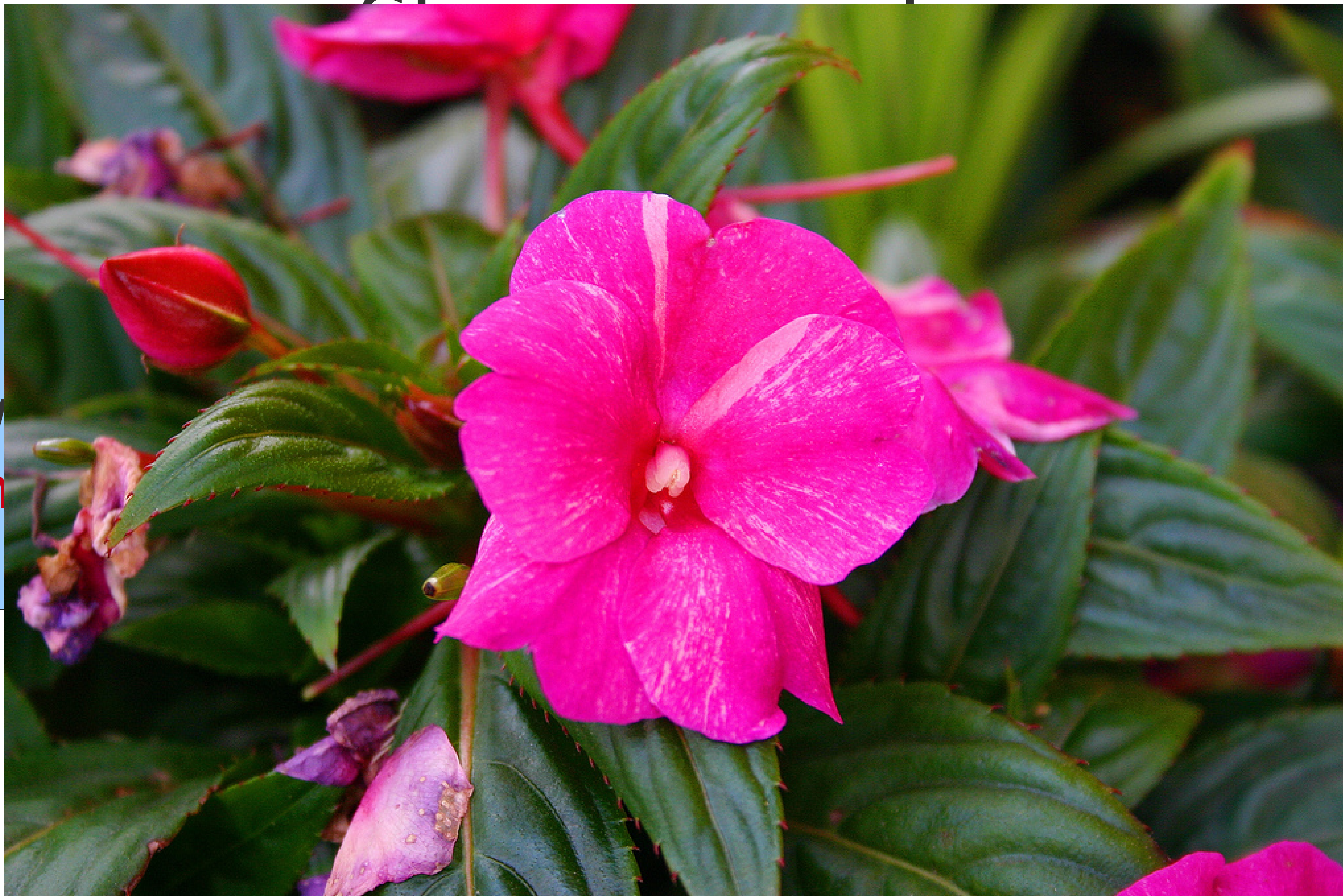
- The act of hiding information
- Often in plain sight...
- Example: slightly modify pixel data...
  - (R,G,B): (255,255,255) → (255,255,254)
- See app: steghide
  - Operates on both images and audio
  - Graph-theoretic basis
  - man steghide

Steganography

- The act of hiding information
- Often in plain sight

When successful, any eavesdropper never knows that a certain message has been transmitted.

    - Operates on both images and audio
    - Graph-theoretic basis
    - man steghide



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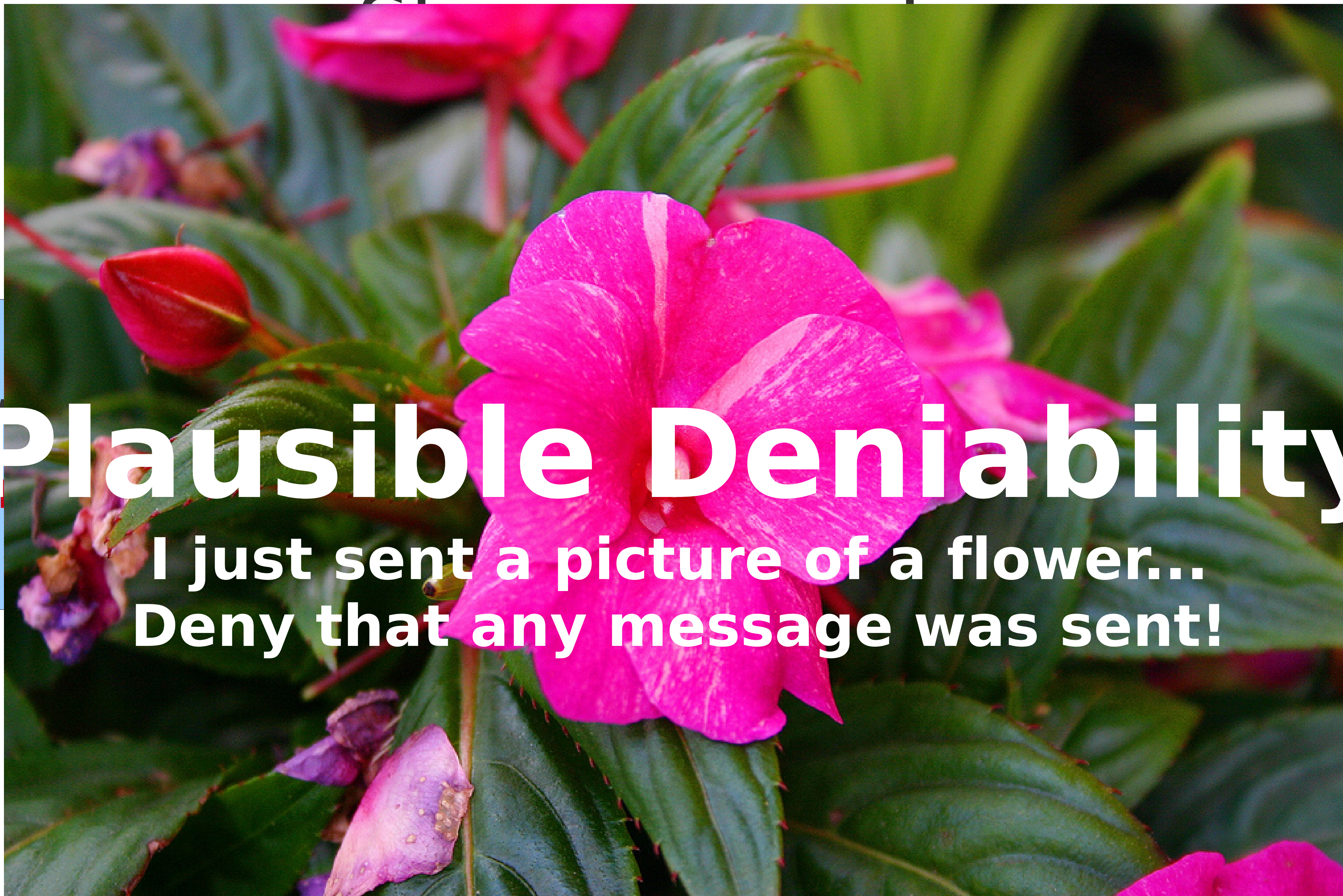


Plausible Deniability

I just sent a picture of a flower…

Deny that any message was sent!

American Revolution, 1775

- *One if by land, two if by sea.*
- American troops depended on this information about British movements
- “Paul Revere's Ride,” Henry Wadsworth Longfellow
- Military message in plain sight
- Plausible deniability—risk of British arrest
- Steganography at work!

Cryptography

- The act of disguising information
- Transforms what is called plain text into cipher text
- Two forms: transposition, and substitution
  - Transposition scrambles the plaintext letters
    - book → kobo
  - Substitution replaces words or characters
    - book → cjjl
    - Two forms: codes, and ciphers
    - Codes replace words for other words
      - book → bird
    - Ciphers replace individual characters
      - Title slide ciphertext: Gur Cbjre bs Xabjyrqtr

The unbreakable cipher

- U.S. Patent 1,310,719
- Vernam Cipher – one-time pad (OTP)
- Mauborgne co-invented—thought of randomness
- Shannon proved it is both unbreakable and fundamental!
- Beautiful simplicity
- Incredibly powerful technology

The unbreakable cipher

- U.S. Patent 1,310,719
- Vernam Cipher – one-time pad (OTP)

The NSA has called this patent "perhaps one of the most important in the history of cryptography."

and fundamental!

- Beautiful simplicity
- Incredibly powerful technology

Is ⊕ a good stream cipher?

Plain Text	Key	Cipher Text
0	0	0
0	1	1
1	0	1
1	1	0

Vernam Cipher Encrypt

Plaintext	“Hi”	
	1101000 1101001	
	⊕⊕⊕⊕⊕⊕⊕ ⊕⊕⊕⊕⊕⊕⊕	
Random OTP Key	1110100 1001101	“tM”
Cipher Text	0011100 0100100	
	“\x1c$”	

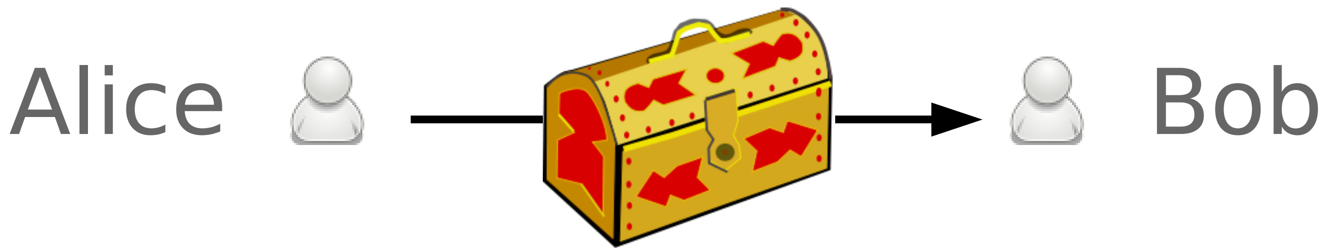
Vernam Cipher Decrypt

Cipher Text	“\x1c$”	
	0011100 0100100	
	⊕⊕⊕⊕⊕⊕⊕ ⊕⊕⊕⊕⊕⊕⊕	
Random OTP Key	1110100 1001101	“tM”
Plain Text	1101000 1101001	
	“Hi”	

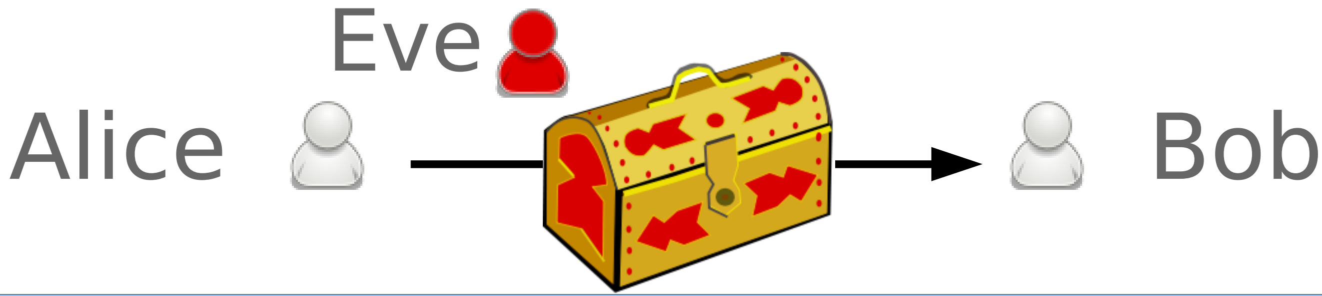
Symmetric Key Cryptography

- Confidentiality via shared keys
- $E_K(M) = C$
- $D_K(C) = M$
- OTP is impractical because key length equals message length
- Alternatives
  - Stream Ciphers: RC4, A5/1,2,3 (GSM...)
  - Block Ciphers: AES, DES, Blowfish

The treasure chest analogy



The treasure chest analogy



Bad, can easily be intercepted and opened,
by the nefarious Eve!

The treasure chest analogy

The treasure chest analogy

Our first very simple protocol.

Hash Message Authentication Code (HMAC, MAC)

- Hash message using a hash keyed with shared key
- Produce MAC
- Alice or Bob verify integrity of messages based on these hashes

Problem: Replay Attacks

- Eve can send messages again...with observed HMAC
- Fix: introducing nonces
- Random bitstrings used only once
- Provides “sessions” for HMACs

Review: Symmetric

- Confidentiality – Stream/Block Ciphers
- Integrity – HMAC
- Authentication – HMAC and nonce

Perfect crypto, what next?

- Yes, we have the technology
- But, we have a different problem
- How can we share the one-time pads?
- Fundamental problem in cryptography:

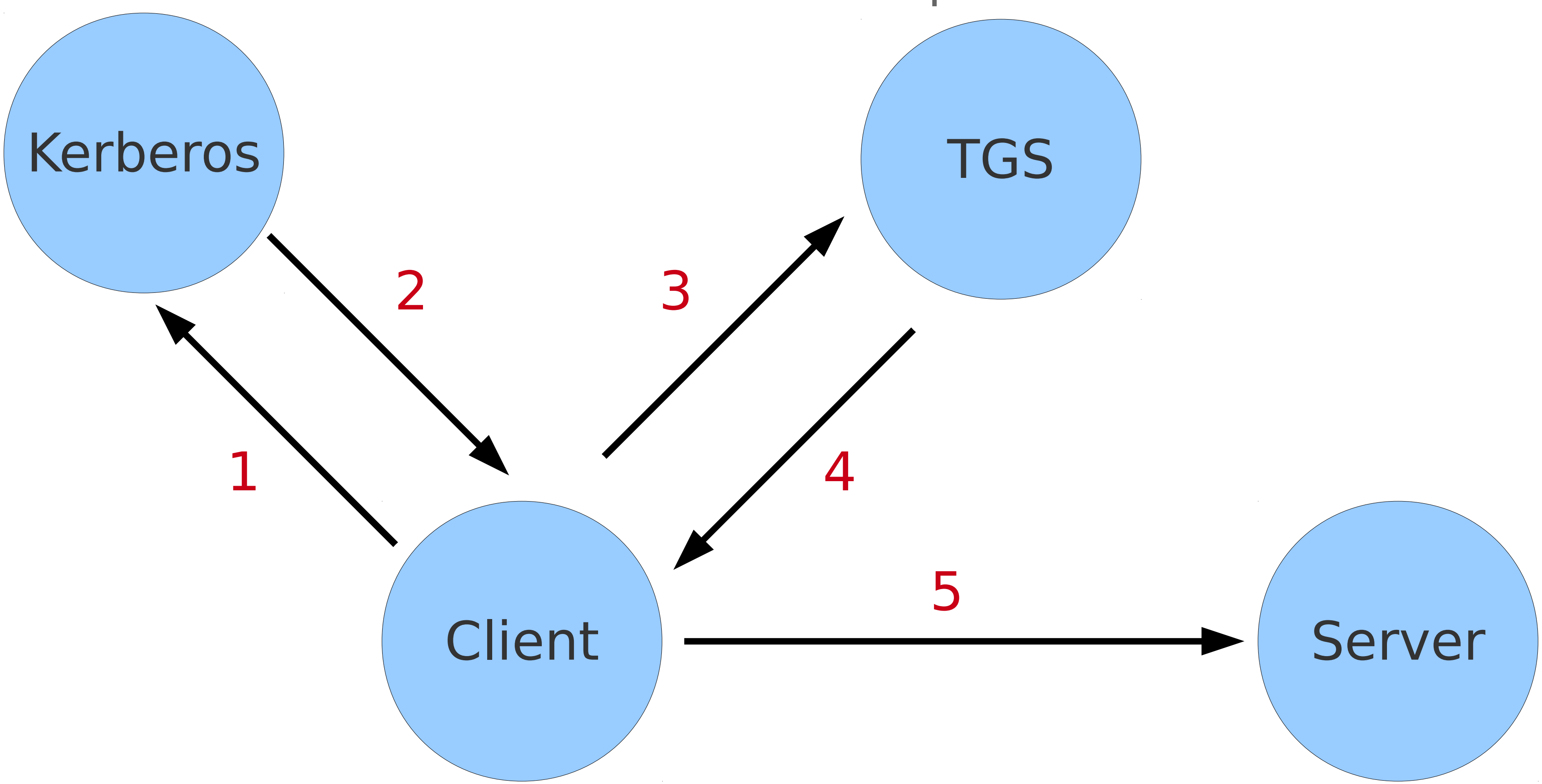
Key Distribution

Kerberos: Central Key DB

- Key Distribution Center
  - Database of clients and secret keys
  - Handles key distribution in symmetric case
- Trusted Arbitrator Service
  - Secure network authentication to servers etc.
- Based on Needham-Schroeder's protocol
- From MIT's Project Athena

Kerberos: Authentication Steps

1. Request for ticket-granting ticket
2. Ticket-granting ticket
3. Request for server ticket
4. Server ticket
5. Request for service



Kerberos: Symbols

Symbol	Meaning
c	client
s	server
a	client address
v	valid times
t	timestamp
K_x	x's secret key
$K_{x,y}$	Session key for x and y
$\{m\}K_x$	m encrypted with K_x
$T_{x,y}$	x's ticket to use y
$A_{x,y}$	Authenticator from x to y

Kerberos: The protocol

K_c – one-way hash of client password

$T_{c,s} = s,\{c,a,v,K_{c,s}\}K_s$ – ticket

$A_{c,s} = \{c,t,key\}K_{c,s}$ – authenticator, session key optional

1. Client to Kerberos: $c,\ tgs$
2. Kerberos to Client: $\{K_{c,tgs}\}K_c,\ \{T_{c,tgs}\}K_{tgs}$
3. Client to TGS: $\{A_{c,s}\}K_{c,tgs},\ \{T_{c,tgs}\}K_{tgs}$
4. TGS to Client: $\{K_{c,s}\}K_{c,tgs},\ \{T_{c,s}\}K_s$
5. Client to Server: $\{A_{c,s}\}K_{c,s},\ \{T_{c,s}\}K_s$

Diffie Hellman Key Exchange [Wikipedia]

	Alice	Evil Eve	Bob
	Alice and Bob exchange a Prime (P) and a Generator (G) in clear text, such that P > G and G is Primitive Root of P **G = 7, P = 11**	**Evil Eve sees** **G = 7, P = 11**	**Alice and Bob exchange a Prime (P) and a Generator (G) in clear text, such that P > G and G is Primitive Root of P** **G = 7, P = 11**
Step 1	Alice generates a random number: X_A X_A=6 (Secret)		Bob generates a random number: X_B X_B=9 (Secret)
Step 2	$Y_A=G^{X_A}(\text{mod } P)$ $Y_A = 7^6 \ (\text{mod } 11)$ $Y_A = 4$		$Y_B=G^{X_B}(\text{mod } P)$ $Y_B = 7^9 \ (\text{mod } 11)$ $Y_B = 8$
Step 3	Alice receives Y_B = 8 in clear-text	Evil Eve sees $Y_A = 4$, $Y_B = 8$	Bob receives Y_A = 4 in clear-text
Step 4	Secret Key $=Y_B^{X_A}(\text{mod } P)$ Secret Key = 8^6 (mod 11) **Secret Key = 3**		Secret Key $=Y_A^{X_B}(\text{mod } P)$ Secret Key = 4^9 (mod 11) **Secret Key = 3**

One-Way Functions

- Given x, `f(x)` is trivial to compute
- Given `f(x)`, x is hard to compute
- Example: increase entropy, break a plate
- Math: what we really want are trapdoor one-way functions

Trapdoor One-Way Functions

- Given `f(x)` and `y`, x is trivial to compute
- `y` is some secret information
- Example: take apart a `x` = watch, pieces = `f(x)`, `y` = assembly instructions
- Math: `16 * 24 = 384`
  - `x = 16, f = *, y = 24`

Trapdoor One-Way Functions

- Given `f(x)` and `y`, x is trivial to compute
- y is some secret information

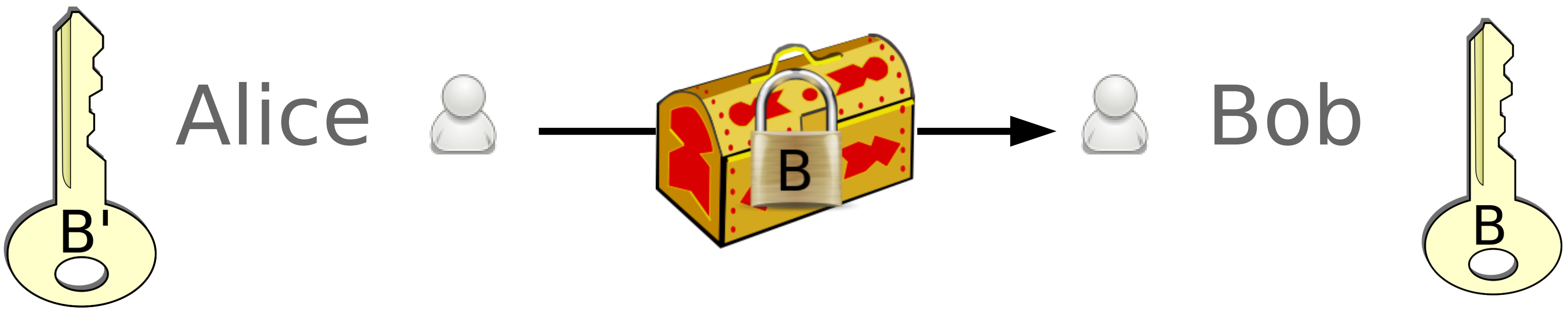
Caveat: No proof these exist, nor even evidence that they can be constructed mathematically.

  - `x = 16, f = *, y = 24`

Asymmetric Key Cryptography

- Confidentiality via private key
- $E_{pub}(M) = C$
- $D_{priv}(C) = M$
- Distribute public key, hide private key
- You made these with `ssh-keygen -t rsa`!
- Very practical, but generally slow
- Often (RSA, etc.) asymmetric methods are used to exchange symmetric keys for fast symmetric ciphers

The treasure chest analogy



The treasure chest analogy

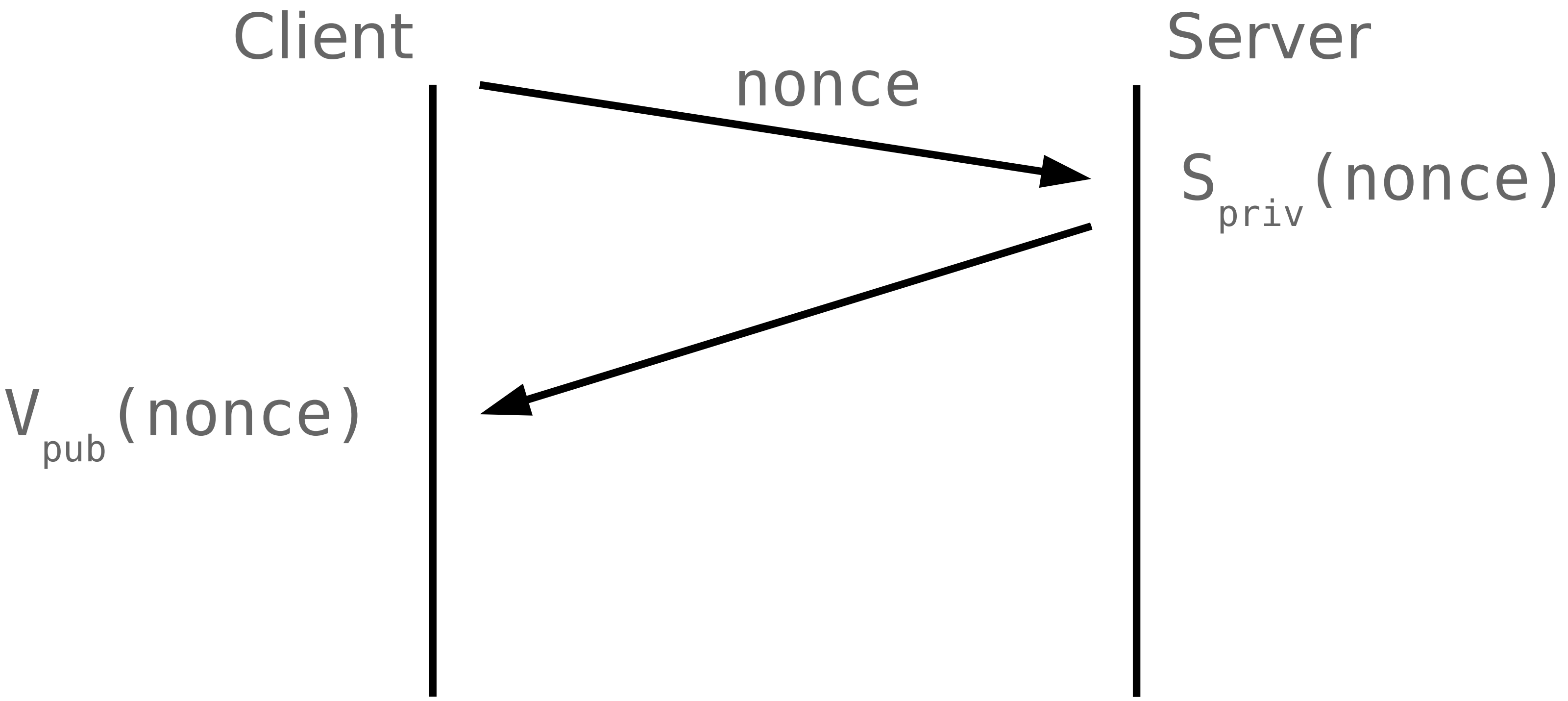
New protocol, no need to have the same key!

Digital Signing

- $S_{priv}(M)$ – sign by encrypting (RSA)
- $V_{pub}(M)$ – verify via decrypting (RSA)
- Can sign entire messages
- But, often signing a hash is good enough
- Hashes are often shorter—quicker to compute

Getting to Identity/Authenticity

- Send a nonce
- Used only once!



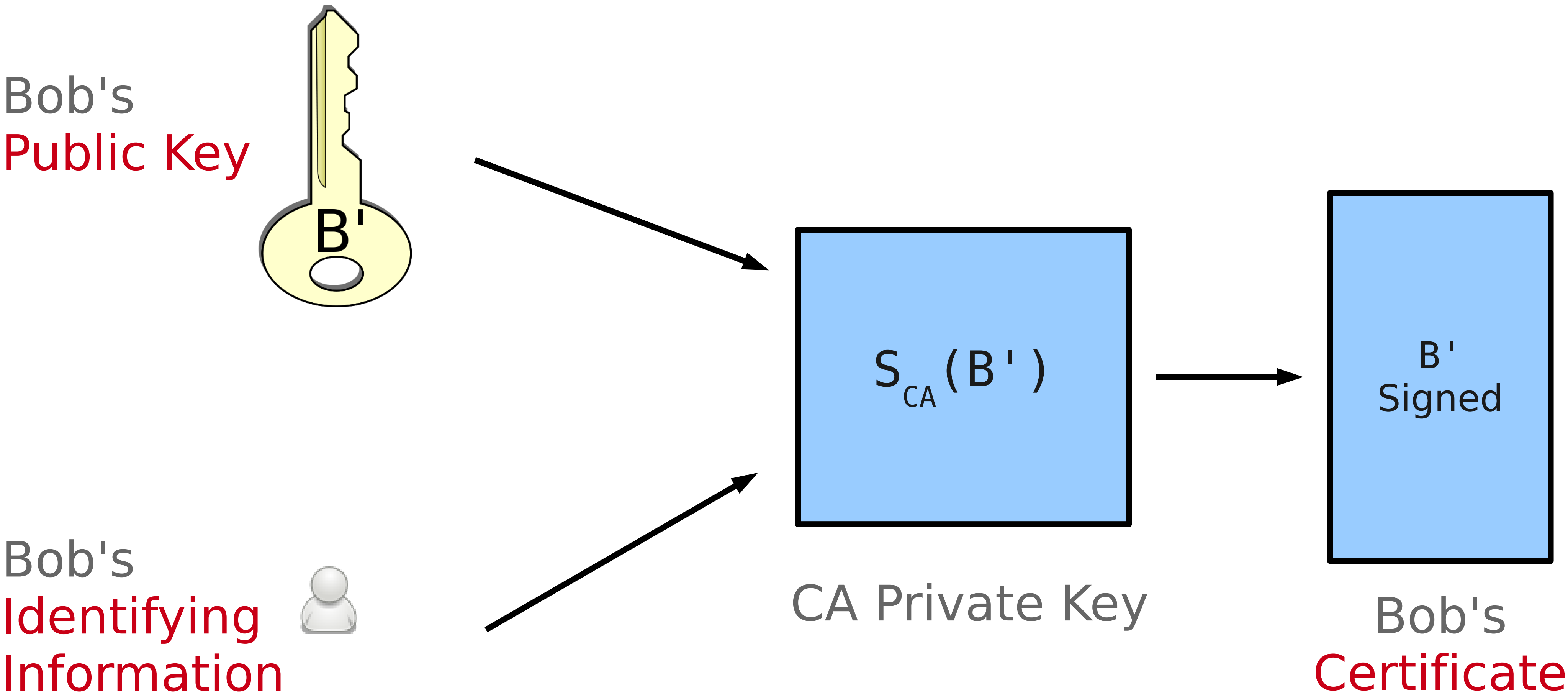
Review: Asymmetric

- Confidentiality – Public key encryption
- Integrity – Sign message with private key
- Authentication – Send a nonce challenge, use sign and verify

Digital Certificates

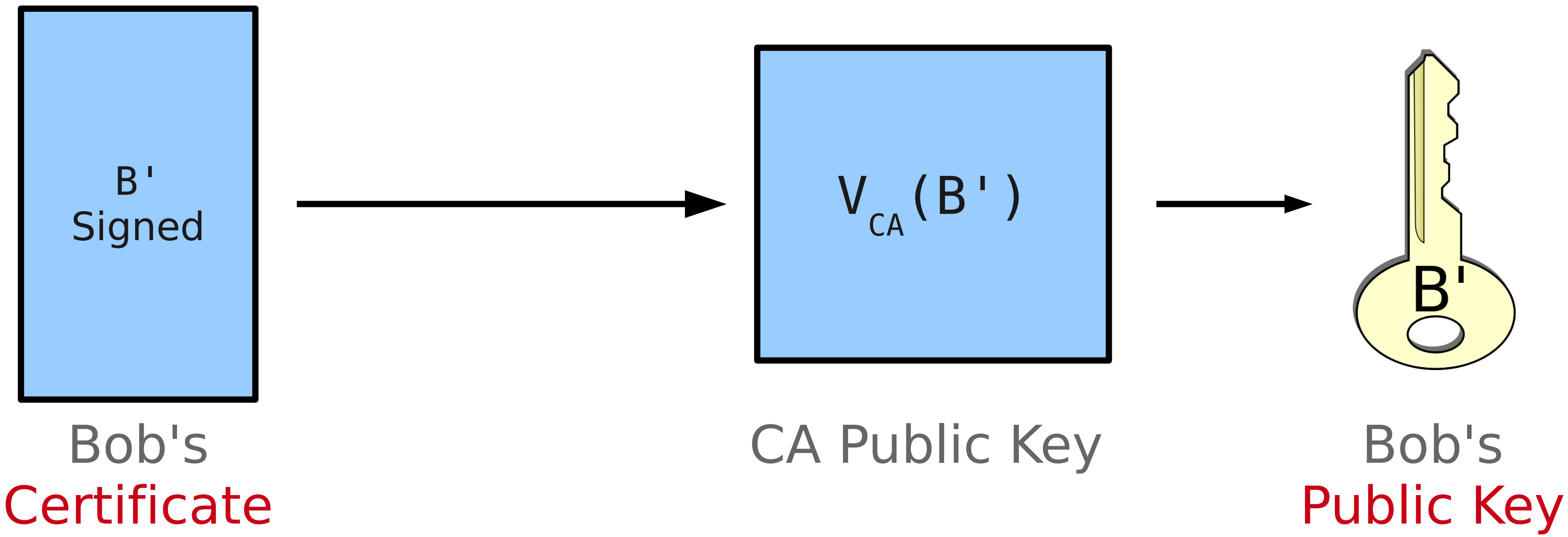
- Issued to prove identity
- Requires trusted third parties
- We call these certificate authorities
- Or just trusted entities in a web of trust
- Used to implement TLS, HTTPS
- x.509 – standardizations

Certificate Authorities: Issue



Certificate Authorities: Usage

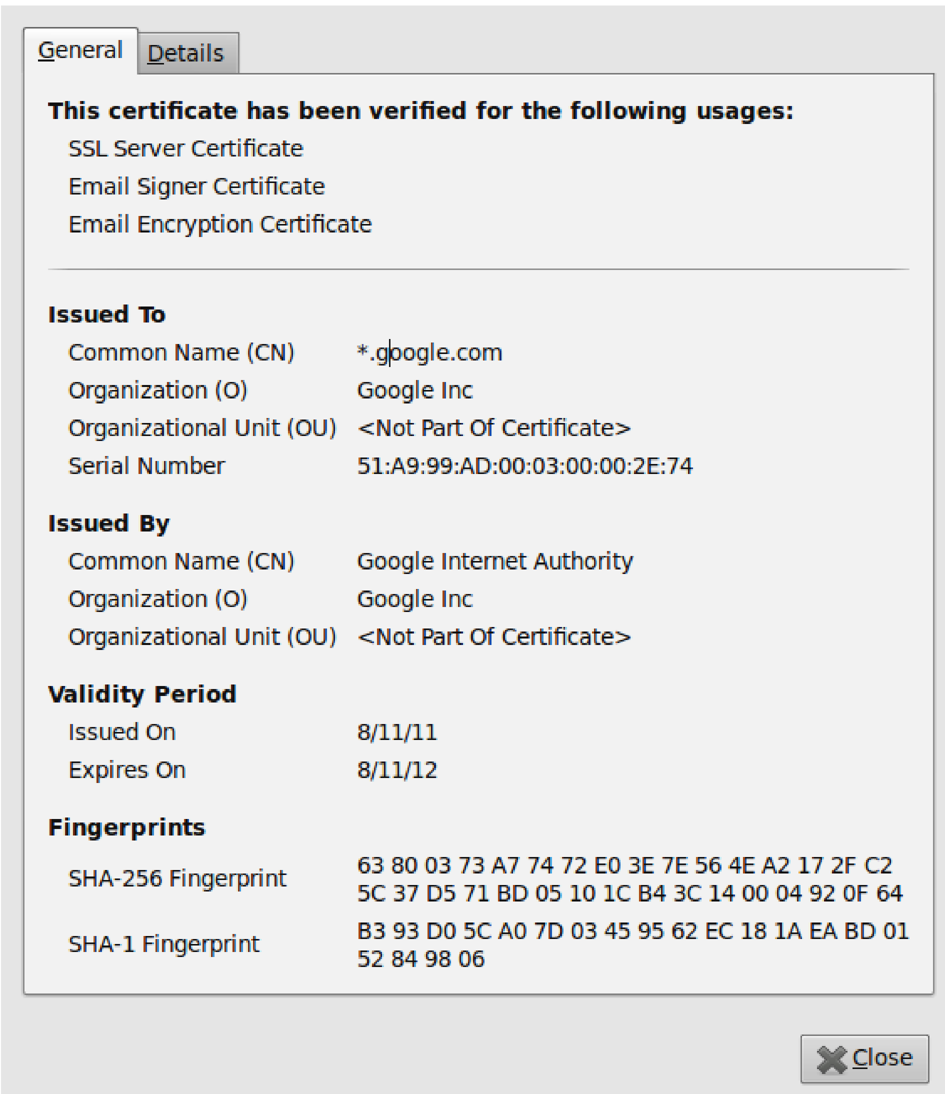
Alice uses the CA's public key to verify Bob's identity and obtain a trustable public key for Bob.

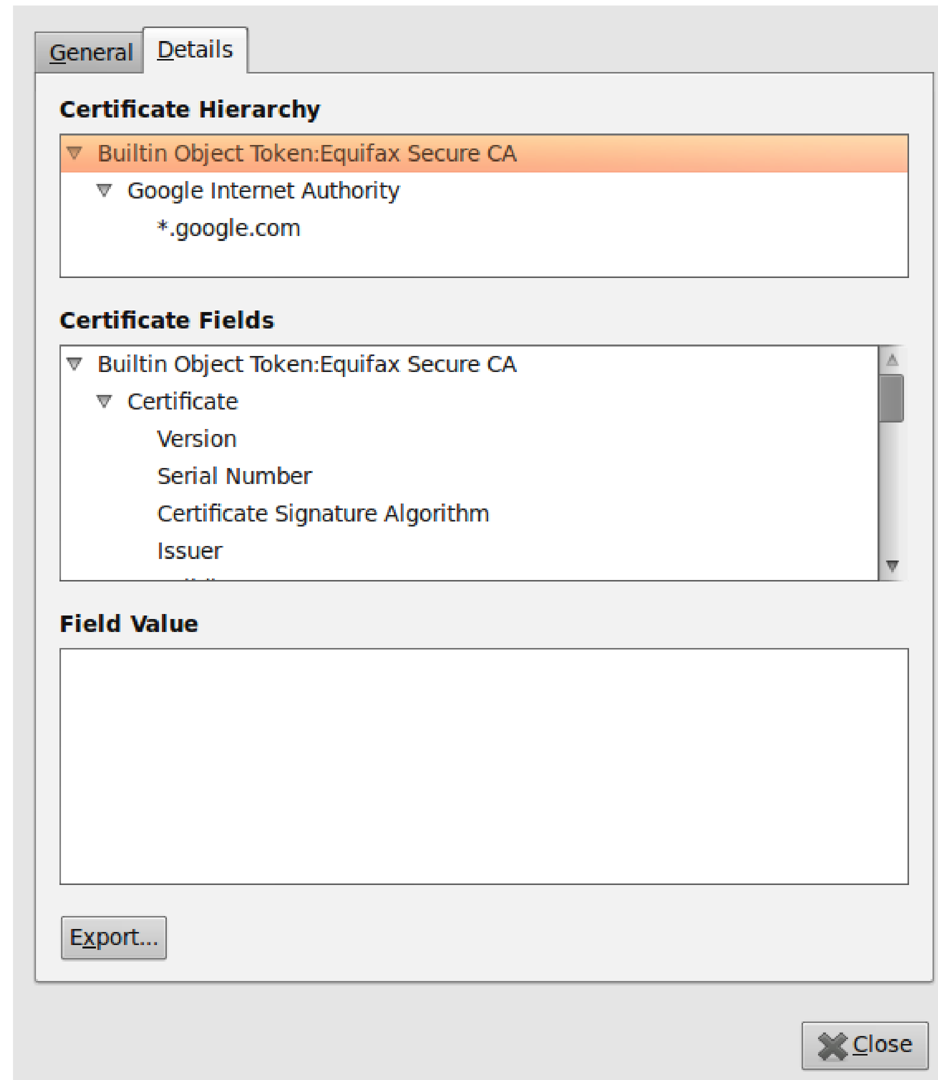


Public Key Infrastructure (PKI)

- Certificate Authorities
  - Bind public keys to certain entities ($K_{B'}$ with Bob)
  - DigiNotar – hacked, along with other CAs
  - Admin Password: Pr0d@dm1n
  - Iranian-based forged Google, and more certificates
- Web of Trust
  - P2P model, let many others sign your public key
  - Place trust in certain signatures
  - GnuPG, PGP → implement this

Really? Yes!

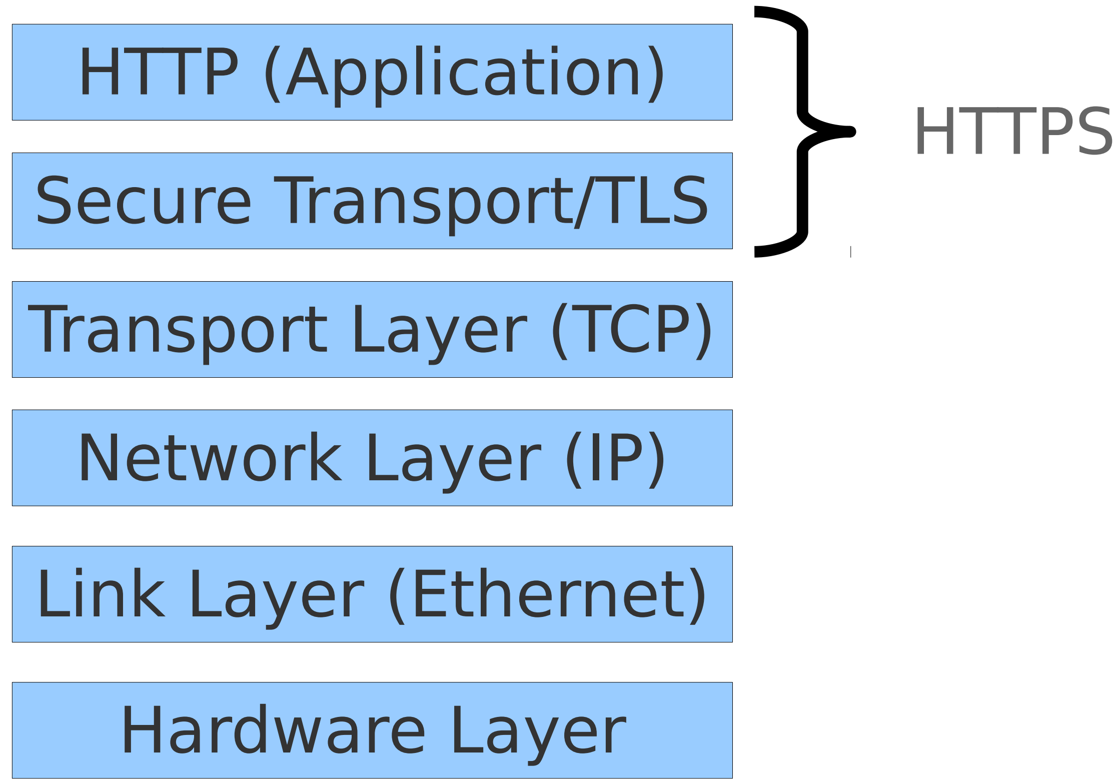

General
Details
This certificate has been verified for the following usages:
SSL Server Certificate
Email Signer Certificate
Email Encryption Certificate
Issued To
Common Name (CN) *.google.com
Organization (O) Google Inc
Organizational Unit (OU) <Not Part Of Certificate>
Serial Number 51:A9:99:AD:00:03:00:00:2E:74
Issued By
Common Name (CN) Google Internet Authority
Organization (O) Google Inc
Organizational Unit (OU) <Not Part Of Certificate>
Validity Period
Issued On 8/11/11
Expires On 8/11/12
Fingerprints
SHA-256 Fingerprint 63 80 03 73 A7 74 72 E0 3E 7E 56 4E A2 17 2F C2 5C 37 D5 71 BD 05 10 1C B4 3C 14 00 04 92 0F 64
SHA-1 Fingerprint B3 93 D0 5C A0 7D 03 45 95 62 EC 18 1A EA BD 01 52 84 98 06
Close


General
Details
Certificate Hierarchy
Builtin Object Token:Equifax Secure CA
Google Internet Authority
*.google.com
Certificate Fields
Builtin Object Token:Equifax Secure CA
Certificate
Version
Serial Number
Certificate Signature Algorithm
Issuer
Field Value
Export...
Close

HTTPS = HTTP+TLS

Netscape made SSL,
IETF made TLS based
on SSL

HTTP is unmodified!



Port 443 is dedicated
for this.

TLS—RFC 2246

- Negotiate

  1) Data integrity hash—HMACs

  2) Symmetric-key cipher for confidentiality (DES, 3DES, AES)

  3) Session key establishment (DH, RSA)

  4) Compression algorithm*
- HMACs and ciphers are keyed in both directions
- 6 keys needed total! All delivered with a shared master secret

TLS Handshaking [RFC 2246]

```
Client                                               Server

ClientHello                  -------->
                                                ServerHello
                                               Certificate*
                                         ServerKeyExchange*
                                        CertificateRequest*
                             <--------      ServerHelloDone
Certificate*
ClientKeyExchange
CertificateVerify*
[ChangeCipherSpec]
Finished                     -------->
                                         [ChangeCipherSpec]
                             <--------             Finished
Application Data             <------->     Application Data

       Figure 1.  Message flow for a full handshake
```

* Indicates optional or situation-dependent messages that are not always sent.

What's going on?

- Negotiation Hello's == protocols, crypto methods, compression
- Server certificate (signed public key)
  - Validate with browser set of CA's
- Client sends encrypted value to server, server decrypts proving private key ownership
- Secret value used to derive symmetric session keys for encryption and MACs

Really? Yes!

Your connection to encrypted.google.com is encrypted with 128-bit encryption.

The connection uses TLS 1.0.

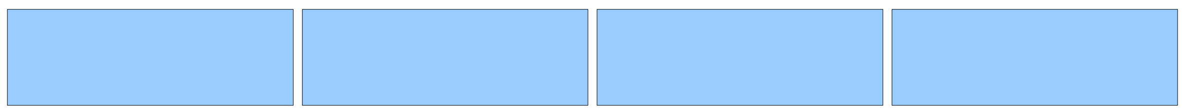
The connection is encrypted using RC4_128, with SHA1 for message authentication and ECDHE_RSA as the key exchange mechanism.

The connection is not compressed.

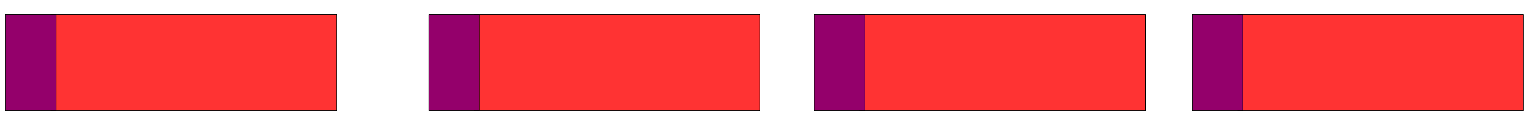
TLS Data Stream

1) Data arrives as stream (TCP expected!)

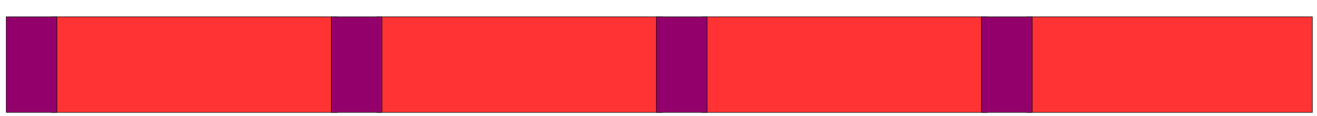
2) TLS segments into chunks



3*) Session key encrypts chunks, MAC algorithm used to create TLS record with short header



4) Records form byte stream for TCP layer



Takeaways

- Serious challenges in communicating securely
- Don't design your own
- Practical solutions combine multiple methods
- Defense in depth is needed in the real-world—cryptography alone is not enough

Resources

- Textbook CH8
- Beware of Snake Oil, Phil Zimmerman
  - Easy read, available online
- Applied Cryptography, Bruce Schneier
- RFC's
- OpenSSL (www.openssl.org)

Fork me on GitHub

GitHub:

git clone git://github.com/theonewolf/15-441-Recitation-Sessions.git