Distributed Systems
Security

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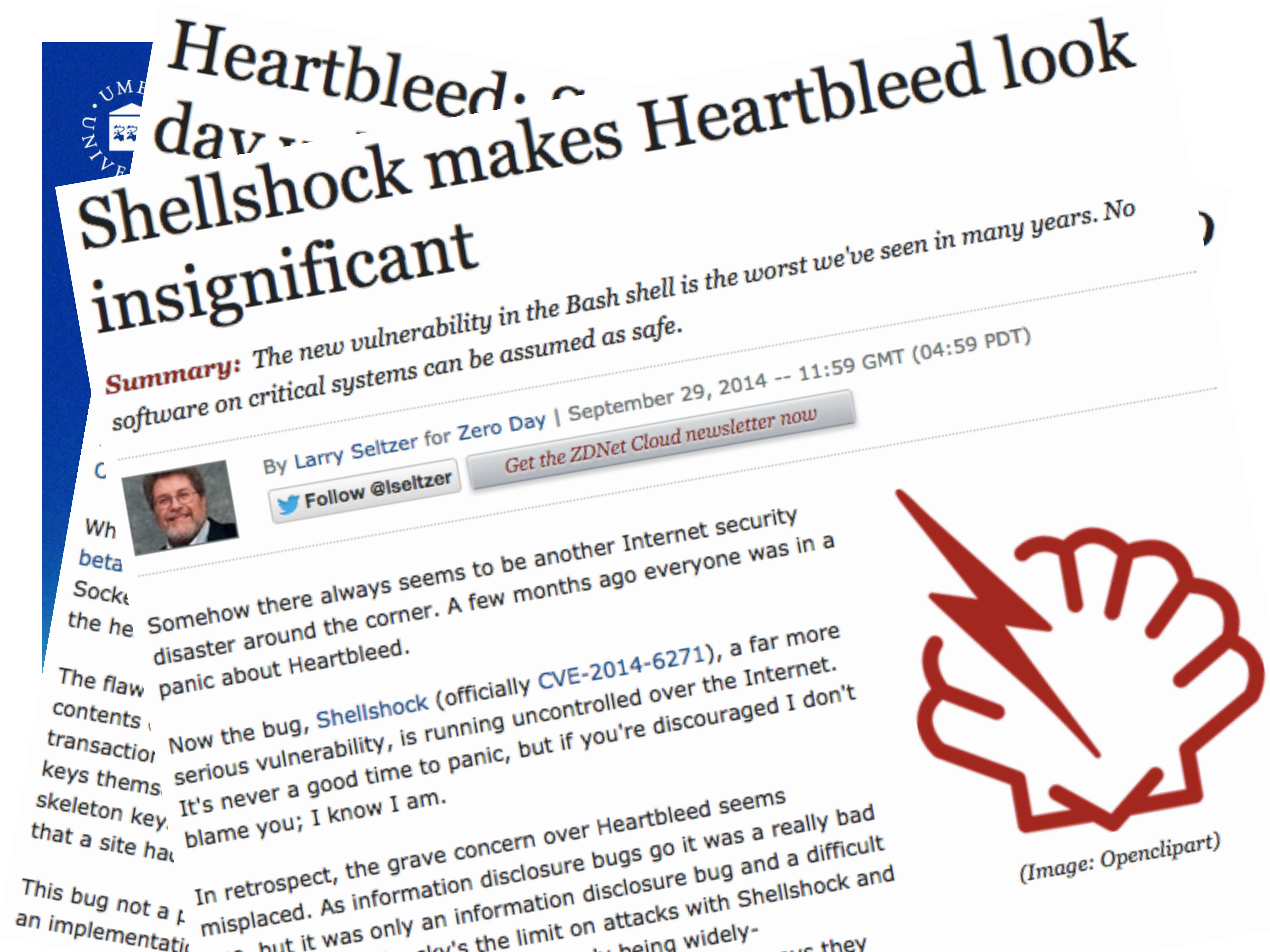
Outline

- Why security?
- What is security?
- Cryptographic algorithms
- Security protocols
- Best practices



Heartbleed: a

day

Shellshock makes Heartbleed look insignificant

Summary: *The new vulnerability in the Bash shell is the worst we've seen in many years. No software on critical systems can be assumed as safe.*

By Larry Seltzer for Zero Day | September 29, 2014 -- 11:59 GMT (04:59 PDT)

Somehow there always seems to be another Internet security disaster around the corner. A few months ago everyone was in a panic about Heartbleed.

Now the bug, Shellshock (officially CVE-2014-6271), a far more serious vulnerability, is running uncontrolled over the Internet. It's never a good time to panic, but if you're discouraged I don't blame you; I know I am.

In retrospect, the grave concern over Heartbleed seems misplaced. As information disclosure bugs go it was a really bad

but it was only an information disclosure bug and a difficult

ky's the limit on attacks with Shellshock and

being widely-

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(Image: Openclipart)

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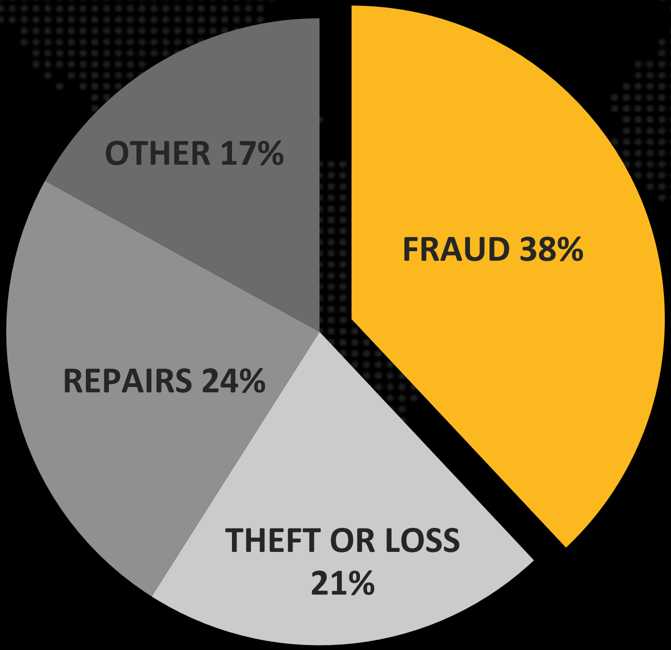
THE GLOBAL PRICE TAG OF CONSUMER CYBERCRIME

$113 BN

ENOUGH TO HOST THE 2012 LONDON OLYMPICS NEARLY 10 TIMES OVER

83% OF DIRECT FINANCIAL COSTS ARE A RESULT OF FRAUD, REPAIRS, THEFT AND LOSS



USD $298

AVERAGE COST PER VICTIM

REPRESENTS A 50 PERCENT INCREASE OVER 2012

http://www.symantec.com/connect/blogs/cybercrime-takes-its-toll

ALL AMOUNTS IN USD

SEE EXTRAPOLATION CALCULATIONS *

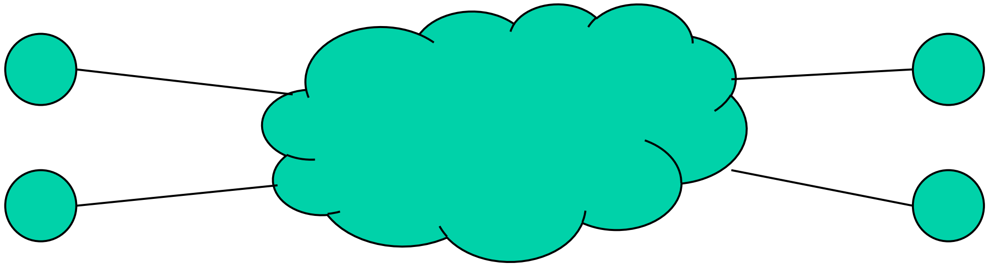
Instead of introduction

- 2012 losses due to hacking
  - Sony: 171 M$
  - Citigroup: 2.7 M$
  - Stratfor:2 M$
  - AT&T: 2 M$
  - Scottrade: 1 M$

http://www.hotforsecurity.com/blog/top-5-corporate-losses-due-to-hacking-1820.html

Why security?

- Distributed systems
  - – Process provide access to resources
  - – Exchange information through a shared network
- One needs to control
  - – Who is accessing the exposed resource
  - – What operations are allowed



What is security? (1/2)

- Three core values
  - Privacy
    - Only authorized principals are allowed to read certain information
  - Integrity
    - Only authorized principals are allows to modify certain information
  - Availability
    - Authorized principals can access information at all times

What is security? (2/2)

- Security policies
  - E.g., user A cannot see user B’s bank statement
  - Technology independent
- Security mechanism
  - E.g., require an ID
  - Technology dependent

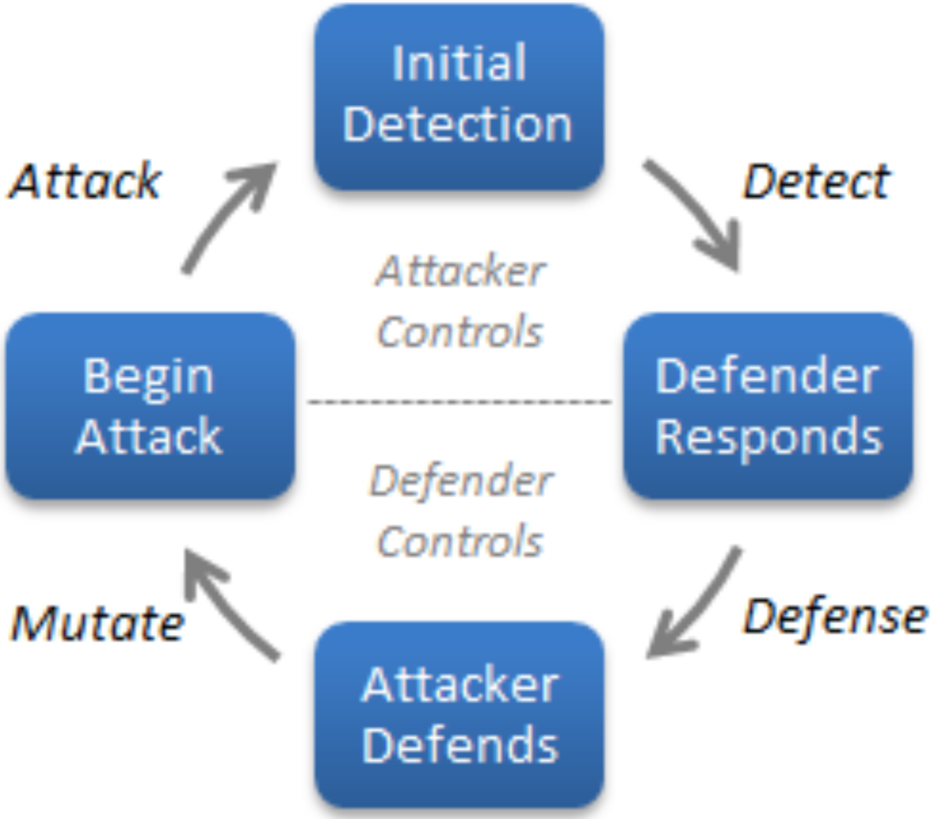
Security goals (1/2)

- Authentication
  - Who are you? Can you prove it?
  - E.g., PIN, password, Eduroam certificate
- Authorization
  - Access Control Lists
    - User A may read/write file F
  - Capabilities
    - Capability C: may read/write file F
    - User A has capability C
- Confidentiality
  - User A and B communicate with one another
  - User E cannot intercept their communication

Security goals (2/2)

- Data integrity
  - Data has only been altered as intended
  - Was file F tampered with?
- Delegation
  - User A is allow to do operation O
  - User A passes this privilege to user B
- Non-repudiation
  - User A signs contract
  - User A cannot deny signature

Computer Attacks and Defenses



Stein et al, Facebook immune system, SNS ‘11

Cryptographic Algorithms

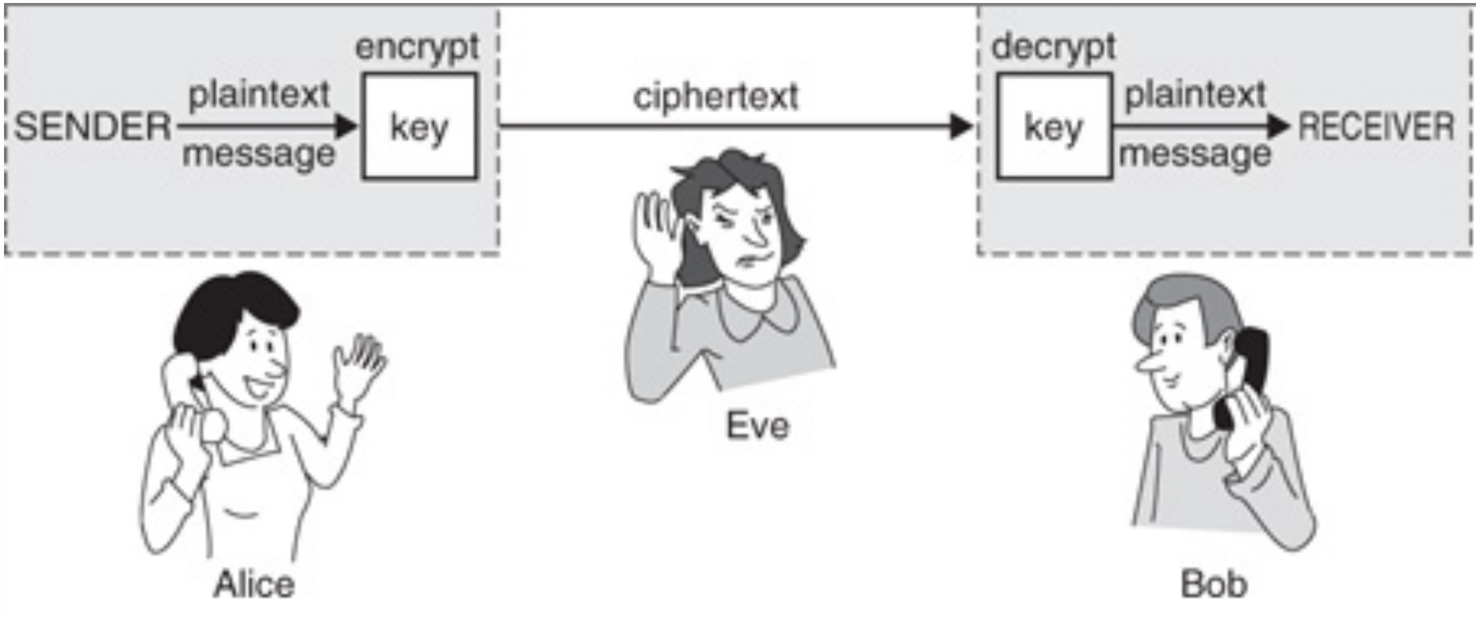
Cryptography

- “the practice and study of techniques for secure communication in the presence of adversaries” (Wikipedia)
- Highly mathematical field
- Cryptology
  - Creating secure algorithms
- Cryptanalysis
  - Breaking secure algorithms

Cryptographic Primitives

- Encryption algorithms
- Hashing algorithms
- Homomorphic encryption

Encryption



http://rosinstrument.com/pb/m/12317.htm

One-time padding

```
Plaintext : hello world
        XOR
Key       : random key
         =
Cyphertext: %^&*#A%323@
            (not actual result)
```

- **Impossible** to crack

- Problem: key length = plaintext length
  - Key distribution?

Encryption: idea

- Invent a secret algorithm (bad)
- Use an open, proven algorithm
  - Keep key(s) secret
- Two families
  - Shared key
    - Block
    - Stream
  - Public key

Block cyphers

- Operate on a fixed block size
  - E.g., 128 bits
  - E(M, K) = M’
  - D(M’, K) = M
- Combine key with plaintext
  - Add, subtract, rotate, shift
  - Obtain confusion and diffusion
- Ideally
  - Key size = cryptographic strength
  - Brute-force attack only
    - 80 bits (okey)
    - 128 bits (strong)
    - 256 bits (very strong)

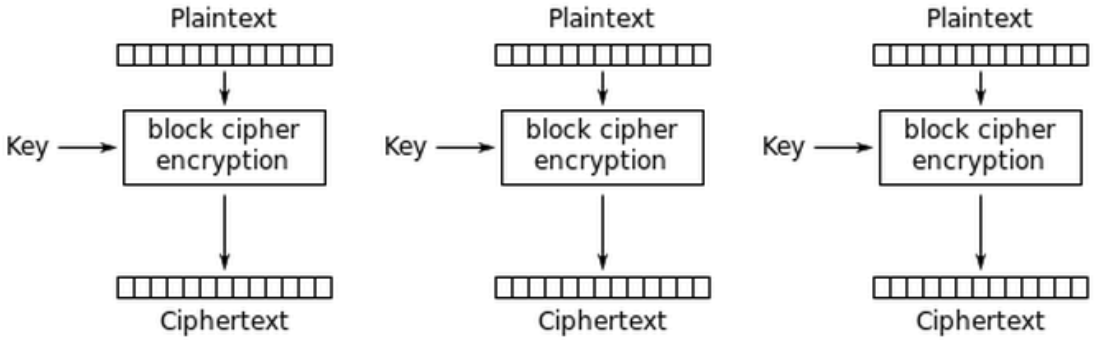
Block cyphers: examples

Name	Key size	Block size
3DES	168	64
Blowfish	32–448	64
IDEA	128	64
AES	128, 192, 256	128

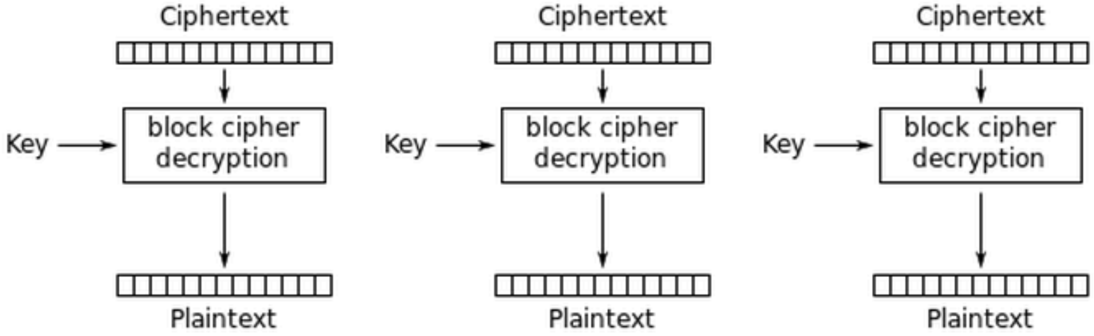
Stream cyphers

- Operates on the whole data
  - E(M, K) = M’
  - D(M’, K) = M
- Can be derived from block cyphers

Stream cyphers: ECB

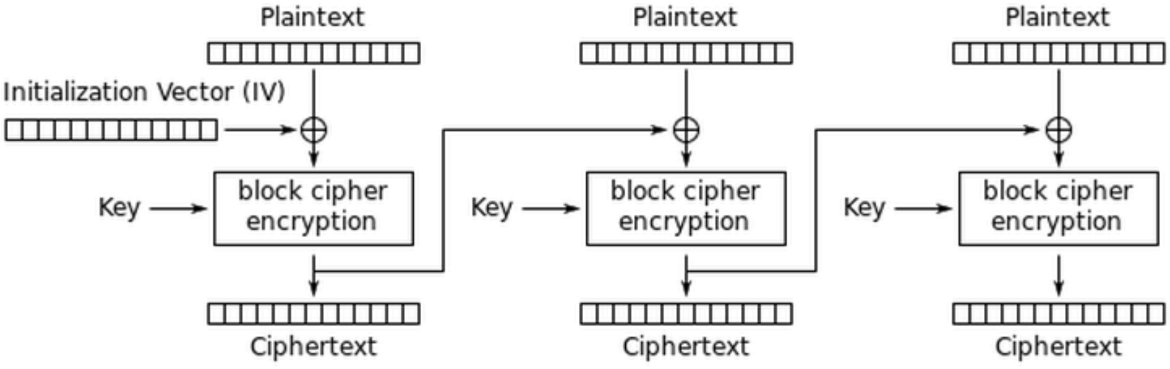


Electronic Codebook (ECB) mode encryption

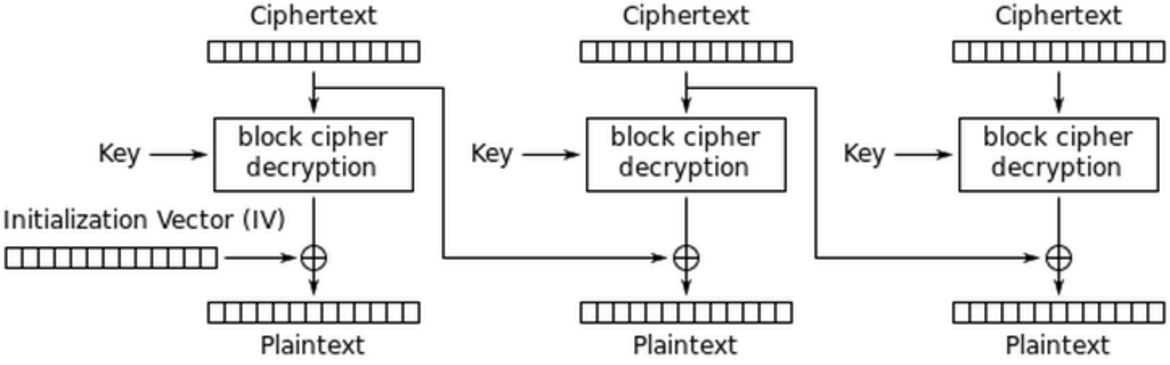


Electronic Codebook (ECB) mode decryption

Stream cyphers: CBC



Cipher Block Chaining (CBC) mode encryption



Cipher Block Chaining (CBC) mode decryption

Other stream cyphers

- Principle
  - “Strong” pseudo-random number generator => keystream
  - XOR keystream with message
- Example
  - RC4 (40–2048 bits security)
- What about key distribution?

Public-key cyphers

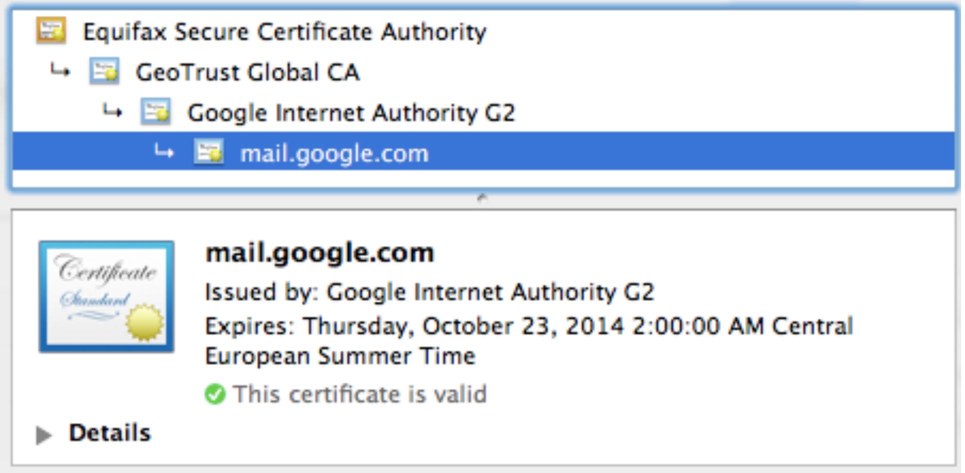
- Idea: two keys
  - Public key used for encryption (Ke)
  - Private key used for decryption (Kd)
  - Algorithm to derive Ke, Kd
  - E(M, Ke) = M’
  - D(M’, Kd) = M   D(M’, **Ke**) **!=** M
  - Cannot compute Kd from Ke
- Based on “hard” problems
  - Integer factorization
  - Discrete logarithm
- Example: DSA, RSA, ECDSA

Signing with a public key

- Goal: ensure a document is authentic
  - Private key (Ks) used for signing
  - Public key (Kv) used for verification
- Example protocol
  - Signer computes S = E(M, Ks)
  - Signer publishes S, M
  - Verifier computes M’ = D(S, Kv)
  - Verifier checks that M = M’

Public key distribution (1/2)

- Out-of-band
  - Face-to-face meeting
  - Sealed envelope etc.
- Public-key infrastructure (PKI)



Equifax Secure Certificate Authority
↳ GeoTrust Global CA
↳ Google Internet Authority G2
↳ mail.google.com

mail.google.com
Issued by: Google Internet Authority G2
Expires: Thursday, October 23, 2014 2:00:00 AM Central European Summer Time
✓ This certificate is valid

▶ **Details**

  - Certificate chain up to a trusted root CA
  - Revocation: expiry (slow), revocation list (fast)
  - E.g., Internet

Public key distribution (2/2)

- Web of trust
  - Certificate: public key, owner (email)…
  - Reciprocal signing of certificates
  - Think social networks
  - Revocation list
  - E.g., Pretty Good Privacy (PGP)

GnuPG

Cryptographic hash functions

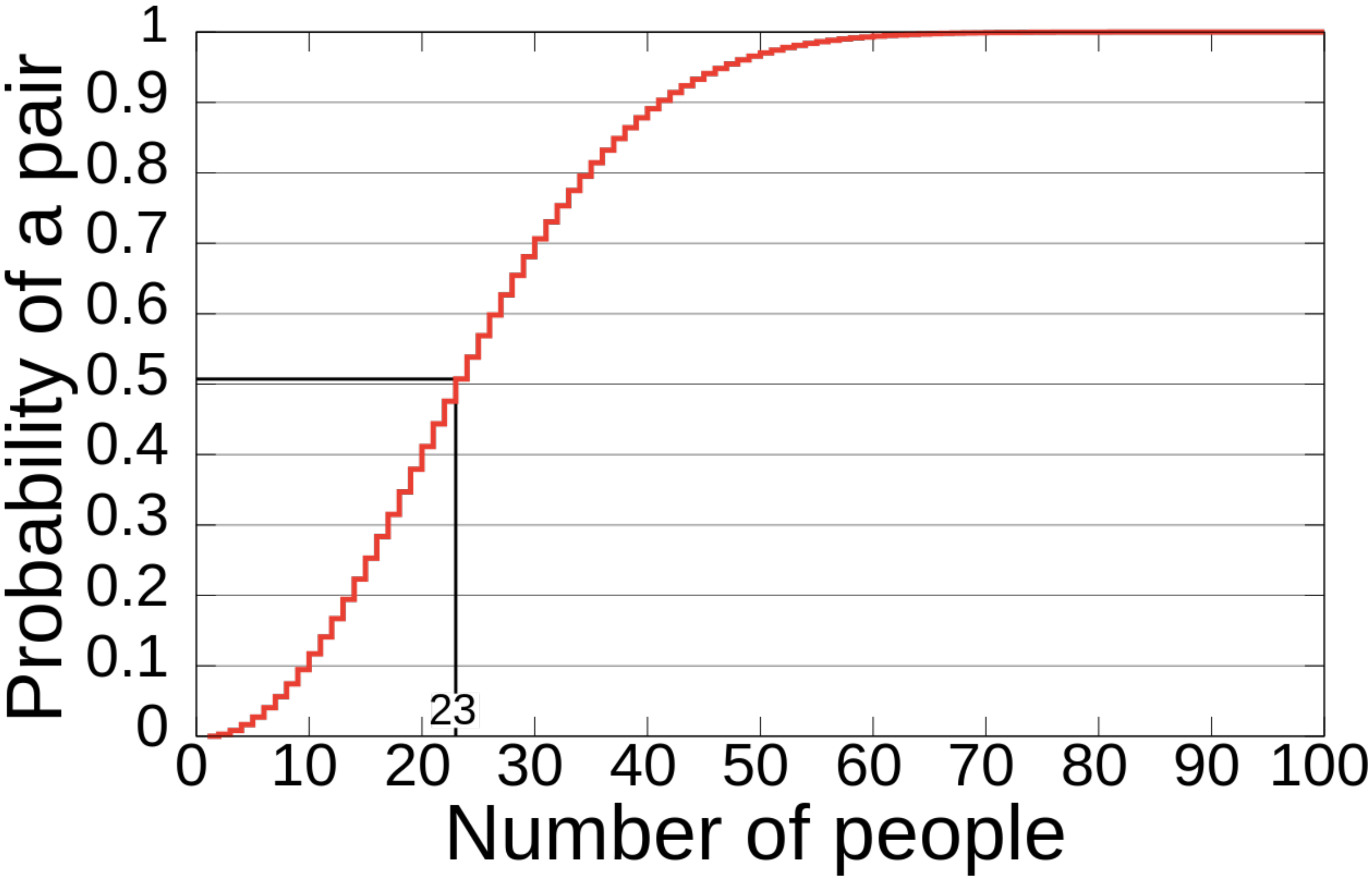
- Problem
  - Public key cyphers only work on small messages
  - Need a method to securely transform large messages into small “summaries”
- Hashing algorithms
  - H(M) = h
  - M = message, arbitrary size
  - H = hash, small (e.g., 128 bits)

Cryptographic hash functions: properties

- H(M) is fast to compute
- If M=M′ then H(M)=H(M′)
- If M≠M′ then H(M)=H(M′) is unlikely
- Given h, infeasible to find M, s.t., H(M)=h
- Cryptographic strength = hash size / 2
  - Due to birthday paradox

MD5	128 bits	Broken
SHA-1	160 bits	Weak
SHA-2 family	256 or 512 bits	
SHA-3 family	256 or 512 bits	

More about the Birthday Paradox



Homomorphic encryption

- Allow receiver to do certain operations on cyphertext without knowing the result
- E.g., process user query over a database
- Fundamentally very slow

Security Protocols

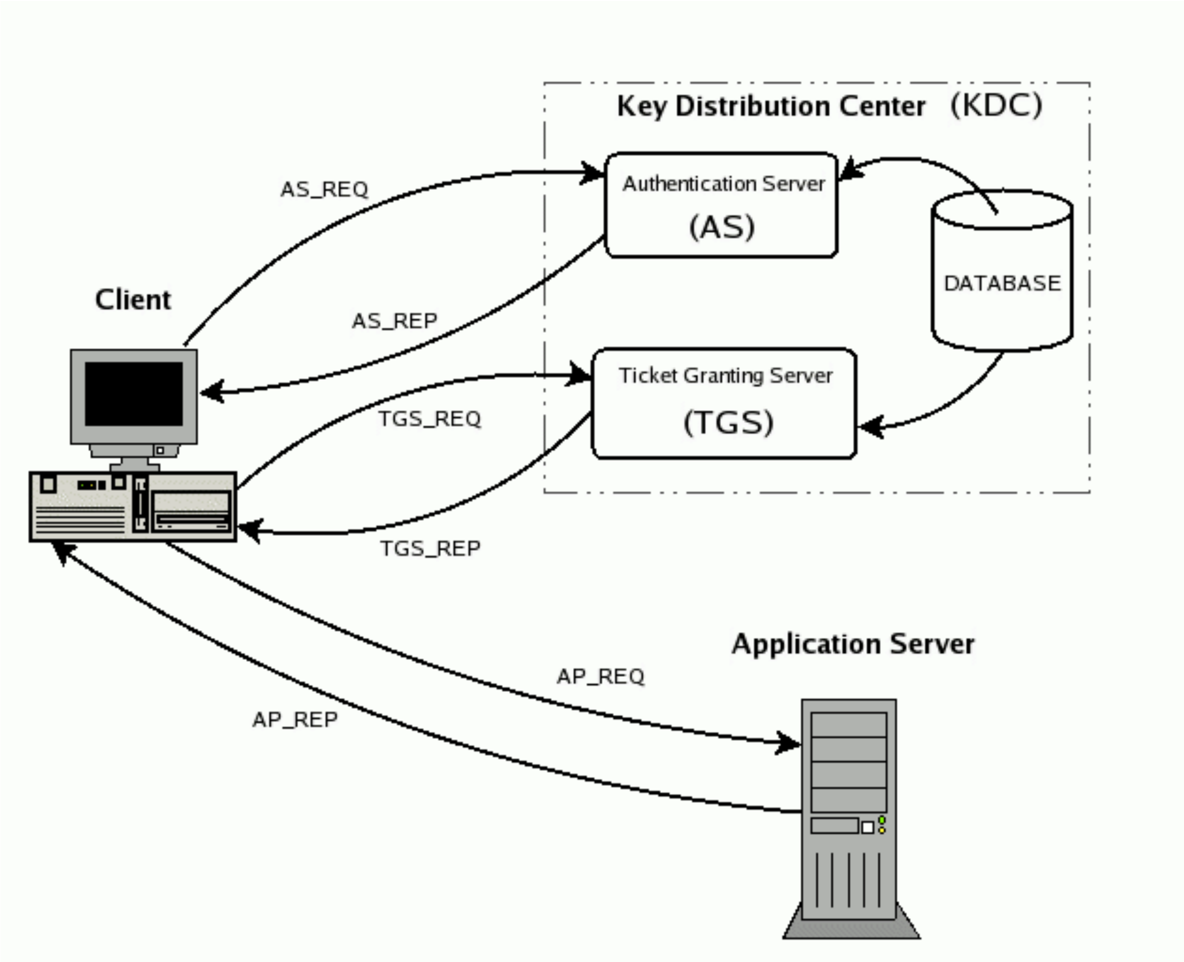
Security protocols

- Kerberos
- TLS

Kerberos

- Client-server model
- Authenticates both client and server
- Uses shared key cryptography
- Requires a trusted **Authentication Server**
- Issues **tickets**

Kerberos: architecture



http://www.zeroshell.org/kerberos/Kerberos-operation/

Kerberos: implementation

- The devil is in the details
- How to convert a password to a shared key?
  - Use a cryptographic hash repeatedly
- How to avoid replay attacks?
  - Use timestamps

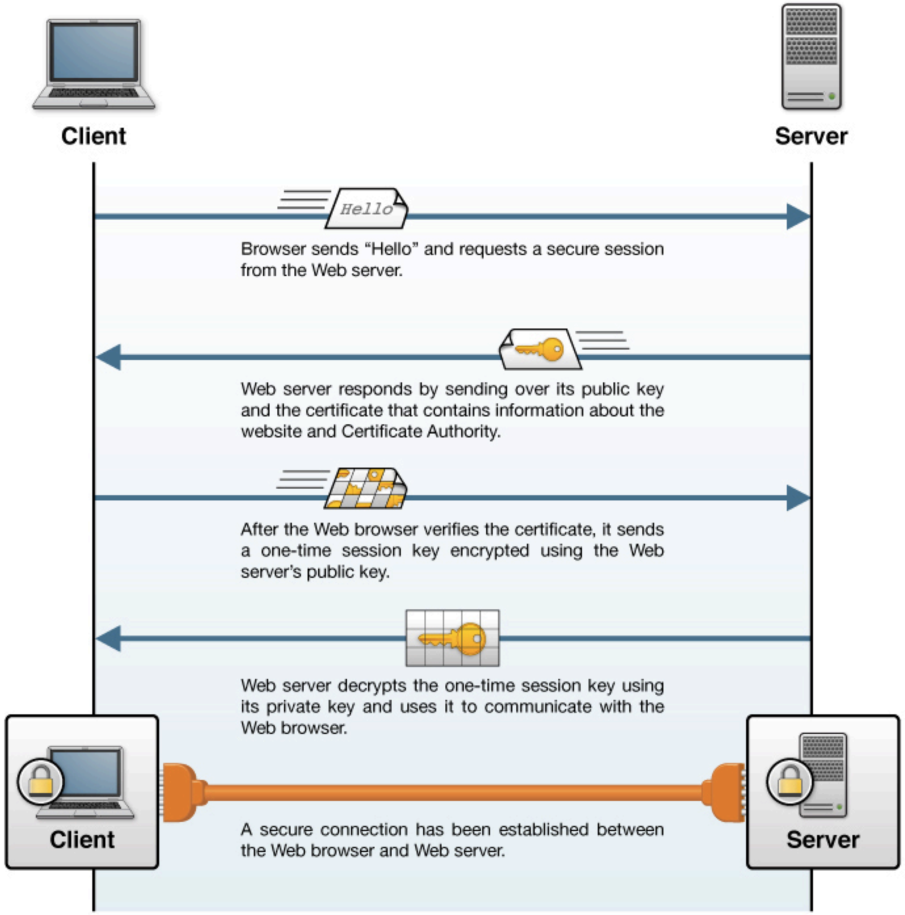
Kerberos: disadvantages

- Single point of failure
- Single point of attack
- Requires synchronized clocks
- Database is centralized
- Clients and servers need to trust and be known by KDC

Transport Layer Security (TLS)

- Client-server model
- Provides mutual authentication
  - Mostly only server is authenticated
- Hybrid encryption
  - Public-key to initialize session
  - Shared key for transmission
- Widely used
  - Internet: HTTPS, email
  - Infrastructure: WiFi, Ethernet

TLS: implementation



Browser sends “Hello” and requests a secure session from the Web server.

Web server responds by sending over its public key and the certificate that contains information about the website and Certificate Authority.

After the Web browser verifies the certificate, it sends a one-time session key encrypted using the Web server’s public key.

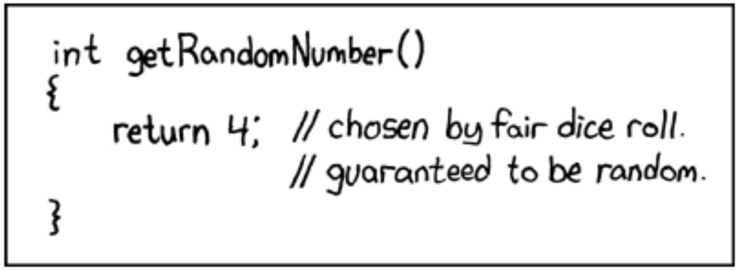
Web server decrypts the one-time session key using its private key and uses it to communicate with the Web browser.

A secure connection has been established between the Web browser and Web server.

http://tech.kaazing.com/documentation/xmpp/3.5/security/c_tls.html

Best Practices

Security bugs (vulnerabilities)



```
int getRandomNumber()
{
    return 4;  // chosen by fair dice roll.
               // guaranteed to be random.
}
```

- Netscape predictable PRNG in 1994
  - Used time-of-day, process ID and parent process ID
  - Session key was predictable
- Debian vulnerability in 2006
  - Uninitialized PRNG
  - Reduced key space to 32768
- Buffer overflows, dangling pointers, SQL injection, …
- Side-channel attacks

Security is difficult

- **Design with security from day 0**
  - Security in depth
- Use known algorithms, techniques, libraries
- Diversify
- Follow vulnerability announcements
  - CVE, Bugtraq, CERT, software-specific
- Do audits
- Review often!
- Do penetration testing

Conclusions

- Distributed systems need to be secure
  - Control how resources are shared
  - Allow them to run over public networks
- Cryptography
  - Encryption
  - Hashing
  - Homomorphic encryption
- Secure protocols
  - Kerberos, TLS, …
- Security is hard
  - Keep up-to-date with best practices