Security, Authentication, Authorization

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CS162 – Operating Systems and Systems Programming

Lecture 26

Dec 3, 2019

Reading: Operating System Concepts Ch15

Plan for Big End-Game

- Computer Security Intro
- @ 2:40 Pintos is alive (Demo)
- Followed by HKN survey time
  - Incentive: 70+% participation => 5+% of final direct from practice test
- Remainder of Security Lecture
- Thurs: CS162 looks under Android
- Next week: Review session in class slot

Goals for Today

- Conceptual understanding of how to make systems secure
- Sense of what happens in practice
  - And what underlies it
- Key security properties
  - Authentication
  - Data integrity
  - Confidentiality
  - Non-repudiation
- Cryptographic Mechanisms

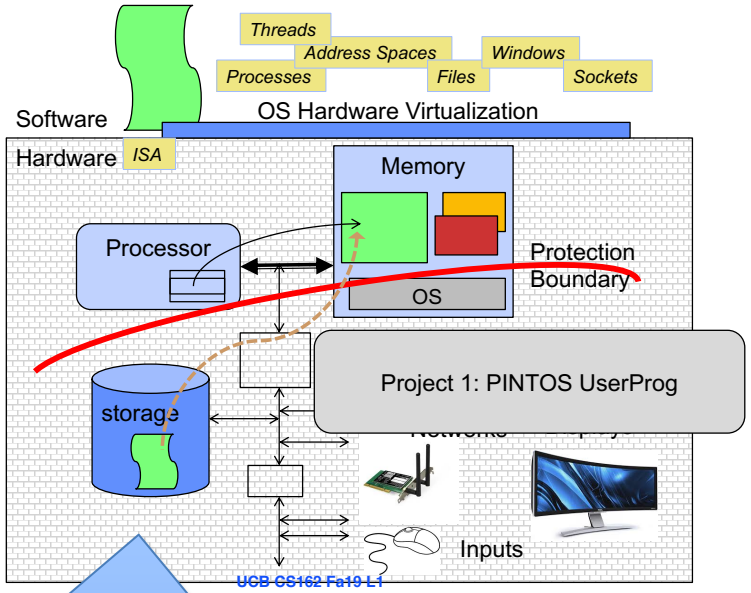
What is Computer Security Today?

- Computing in the presence of an adversary!
  - *Adversary* is the security field's defining characteristic
- Reliability, robustness, and fault tolerance
  - Dealing with Murphy's Law (random failures)
- Security
  - Dealing with actions of a knowledgeable attacker dedicated to causing harm
  - Surviving malice, and not just mischance
- Wherever there is an adversary, there is a computer security problem!

Protection useless without Security

Username: _root____
Passwd: __admin_____

Creating Process & Loading a Program



Protection vs. Security

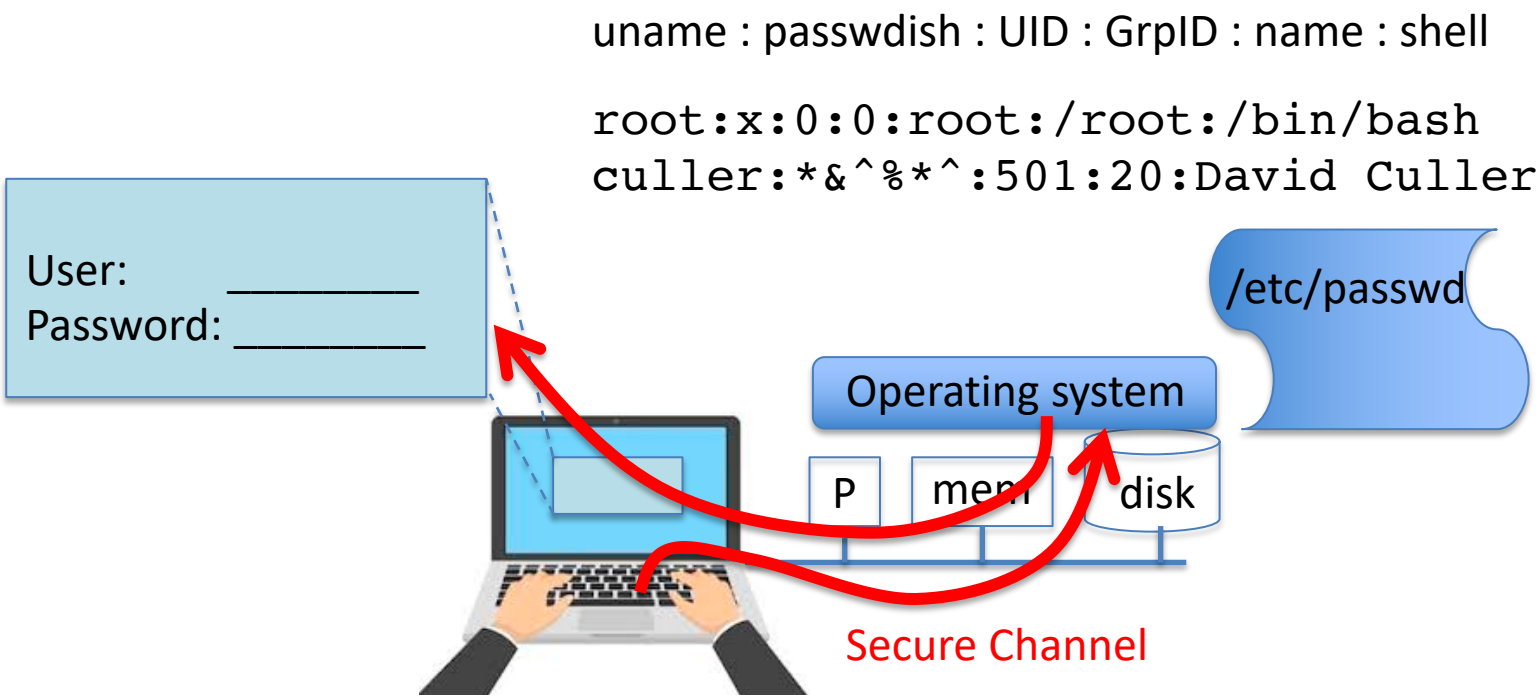
- Protection: mechanisms for controlling access of programs, processes, or users to resources
  - Privileged modes
  - Address Translation (Page table) mechanism
  - Preemptive scheduling
  - File access modes, Data encryption, …
- Security: use of protection mech. to prevent misuse of resources
  - Misuse defined with respect to policy
    - E.g.: prevent exposure of certain sensitive information
    - E.g.: prevent unauthorized modification/deletion of data
  - Need to consider external environment the system operates in
    - Most well-constructed systems cannot protect information if user accidentally reveals password – social engineering challenge

Security Requirements

- **Authentication**
  - Ensures that a user (principal) is who is claiming to be
  - Or the system is who/what it claims to be
- **Integrity (data integrity)**
  - Ensure that data is not changed from source to destination or after being written on a storage device
- **Confidentiality**
  - Ensures that data is read only by authorized users

- **Non-repudiation**
  - Sender/client can't later claim didn't send/write data
  - Receiver/server can't claim didn't receive/write data

The Basic Authentication Loop



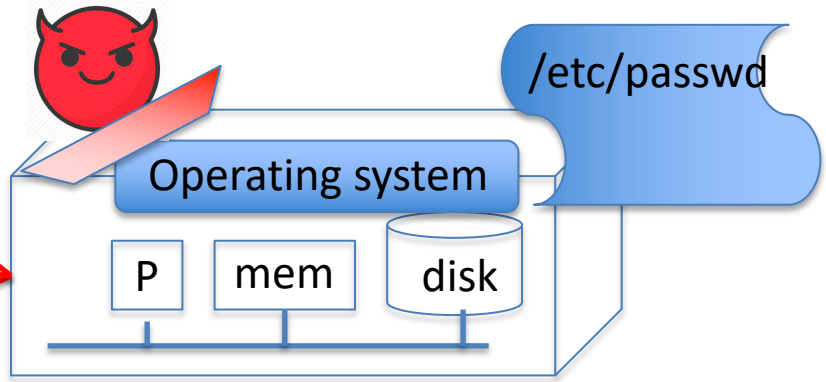
- Trusted system presents "itself"
- Principal provides Identity & Credentials
  - To prove that it IS that identity, system verifies
- Over a secure channel

Or when Unix was Bourne

Secure Channel

uname : passwdish : UID : GrpID : name : shell

```
root:x:0:0:root:/root:/bin/bash
culler:x:501:20:David Culler:/bin/tcsh
```



- User profile (ID, Grp, Name, …) in /etc/passwd too, so many system utilities need to read it – all can !!!
  - Access rights are derived from /etc/passwd entry
- Cannot store password in /etc/passwd
  - Store hash(password), login computes hash and validates
  - Even the system doesn't know the passwd
- Vulnerable to hash attack
  - Hash lots of likely passwds and see if any match

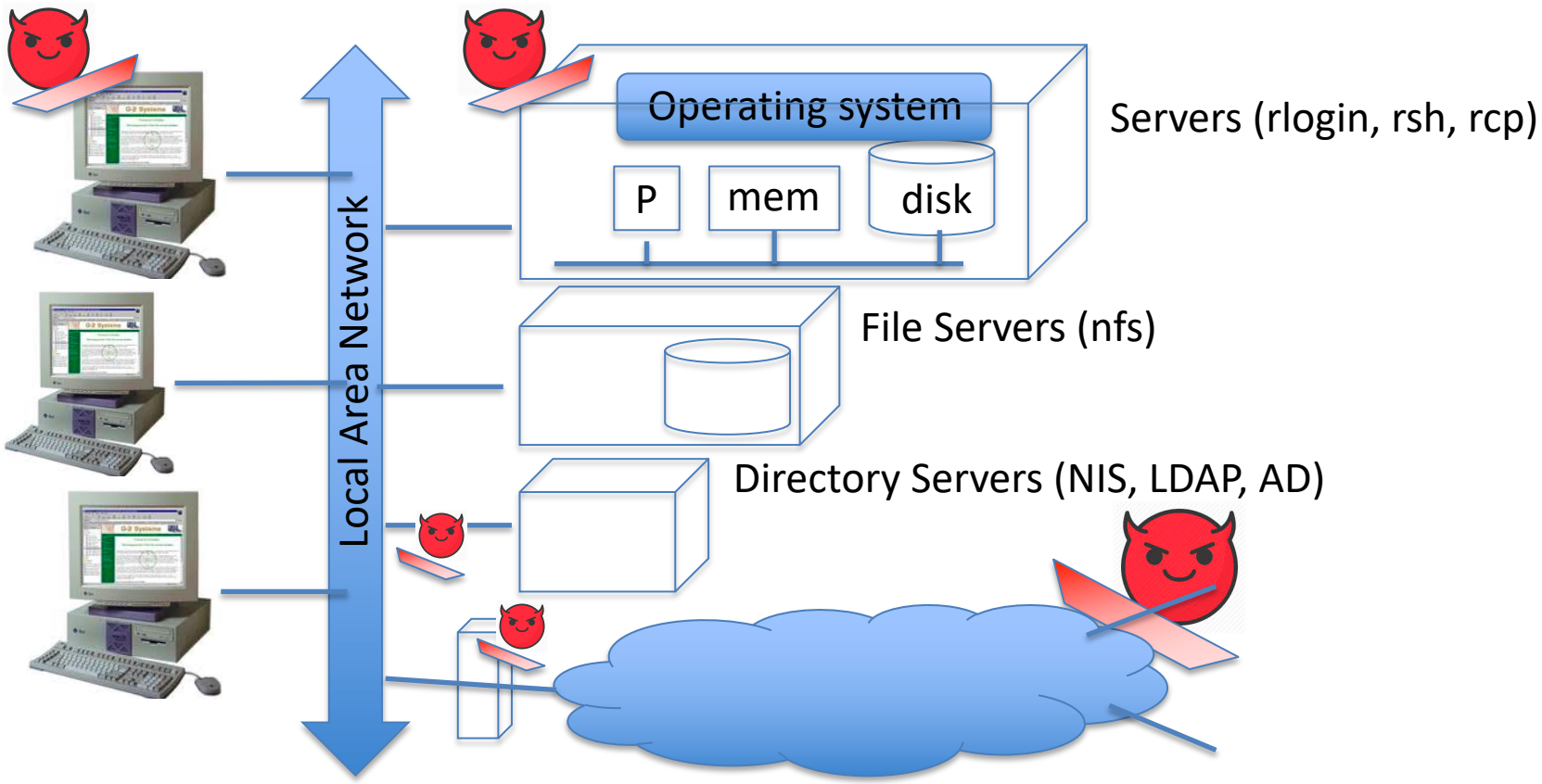
Authentication: Passwords

- Shared secret between two parties
- Since only user knows password, someone types correct password ⇒ must be user typing it
- Very common technique
- System keep copy of secret (or something derived from secret) to check against
  - What if malicious user gains access to list of passwords?
    - Need to obscure information somehow
  - Mechanism: utilize a transformation that is difficult to reverse without the right key (e.g., encryption)

Passwords: Secrecy

- Example: UNIX /etc/passwd file
  - passwd→one way transform(hash)→ encrypted passwd
  - System stores only encrypted version, so OK even if someone reads the file!
  - When you type in your password, system compares encrypted version
- Further measures
  - OS adds a "salt" (long untypable string) to whatever user provides
  - **`uname : hash(salt+passwd) : salt-grain`** kept in `/etc/shadow`

LANs, Internet, …



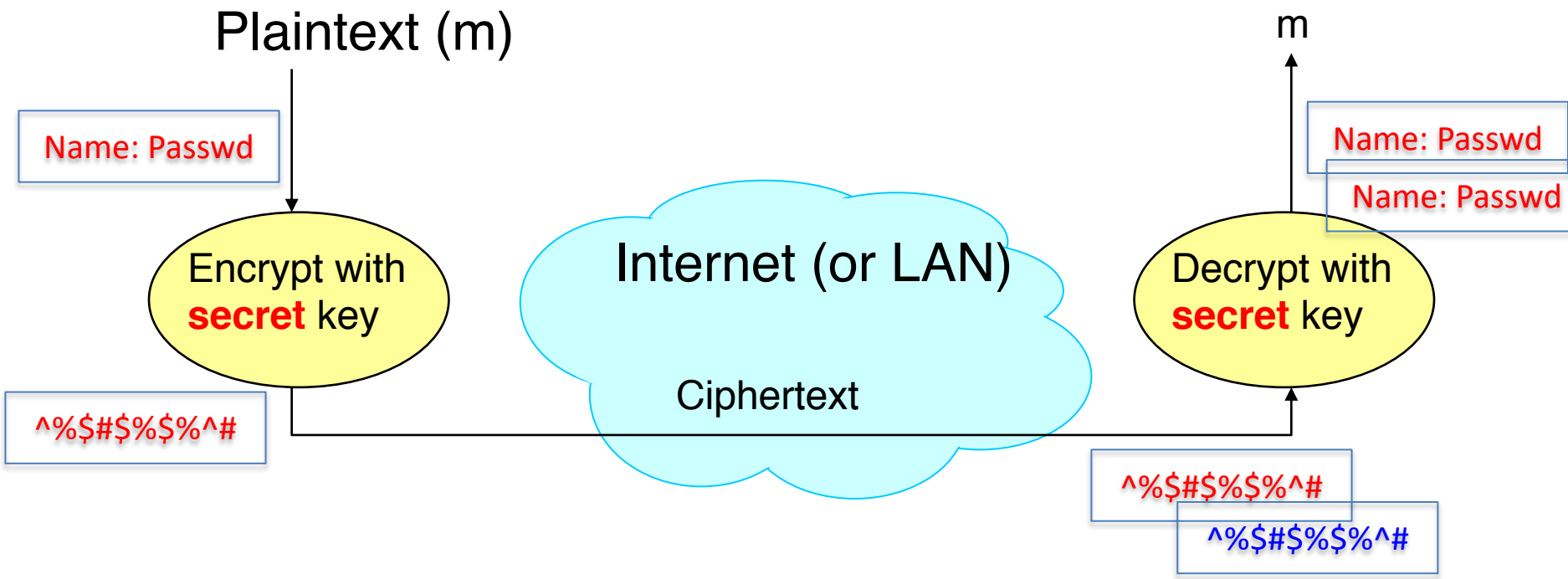
- No inherent secure channel, broad attack surface
- Delegate authentication and authorization to specialized servers
  - Network Information Service (NIS, NIS+)
  - Lightweight Directory Access Protocol (LDAP)
  - Active Directory

Securing Communication: Cryptography

- Cryptography: *communication in the presence of adversaries*
- Studied for thousands of years
  - See the Simon Singh's *The Code Book* for an excellent, highly readable history
- Central goal: **confidentiality**
  - How to encode information so that an adversary can't extract it, but a friend can
- General premise: there is a key, possession of which allows decoding, but without which decoding is infeasible
  - Thus, key must be kept secret and not guessable

Using Symmetric Keys

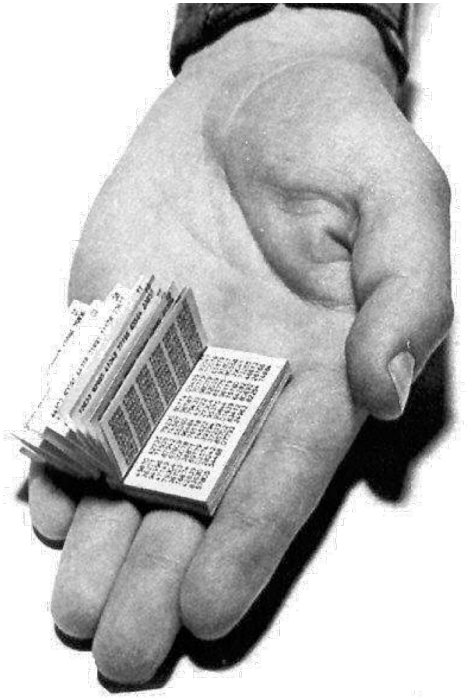
- Same key for encryption and decryption
- Achieves confidentiality
- *Vulnerable to tampering and replay attacks*

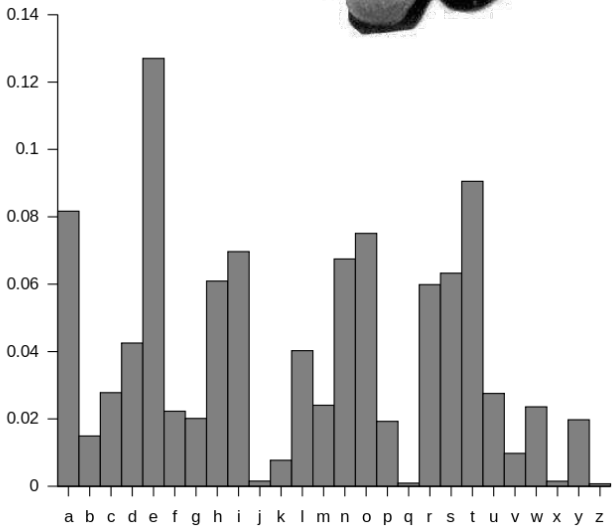


Need integrity check and unique sequence number

Symmetric Keys

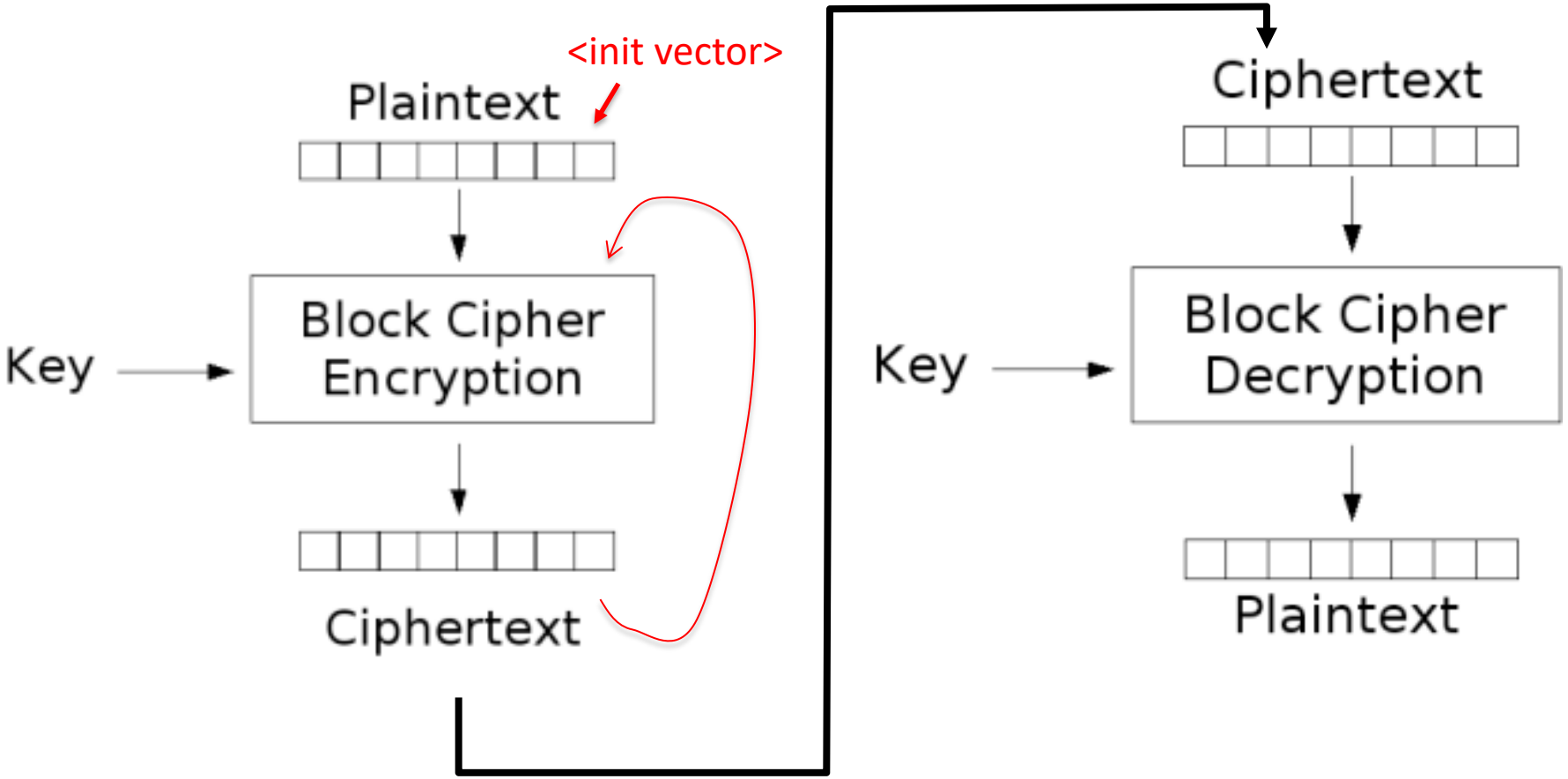
- Can just XOR plaintext with the key
  - Easy to implement, but easy to break using frequency analysis
  - Unbreakable Alternative: XOR with one-time pad
    - Use a different key for each message
    - Need a lot of them in advance





Symmetric Keys

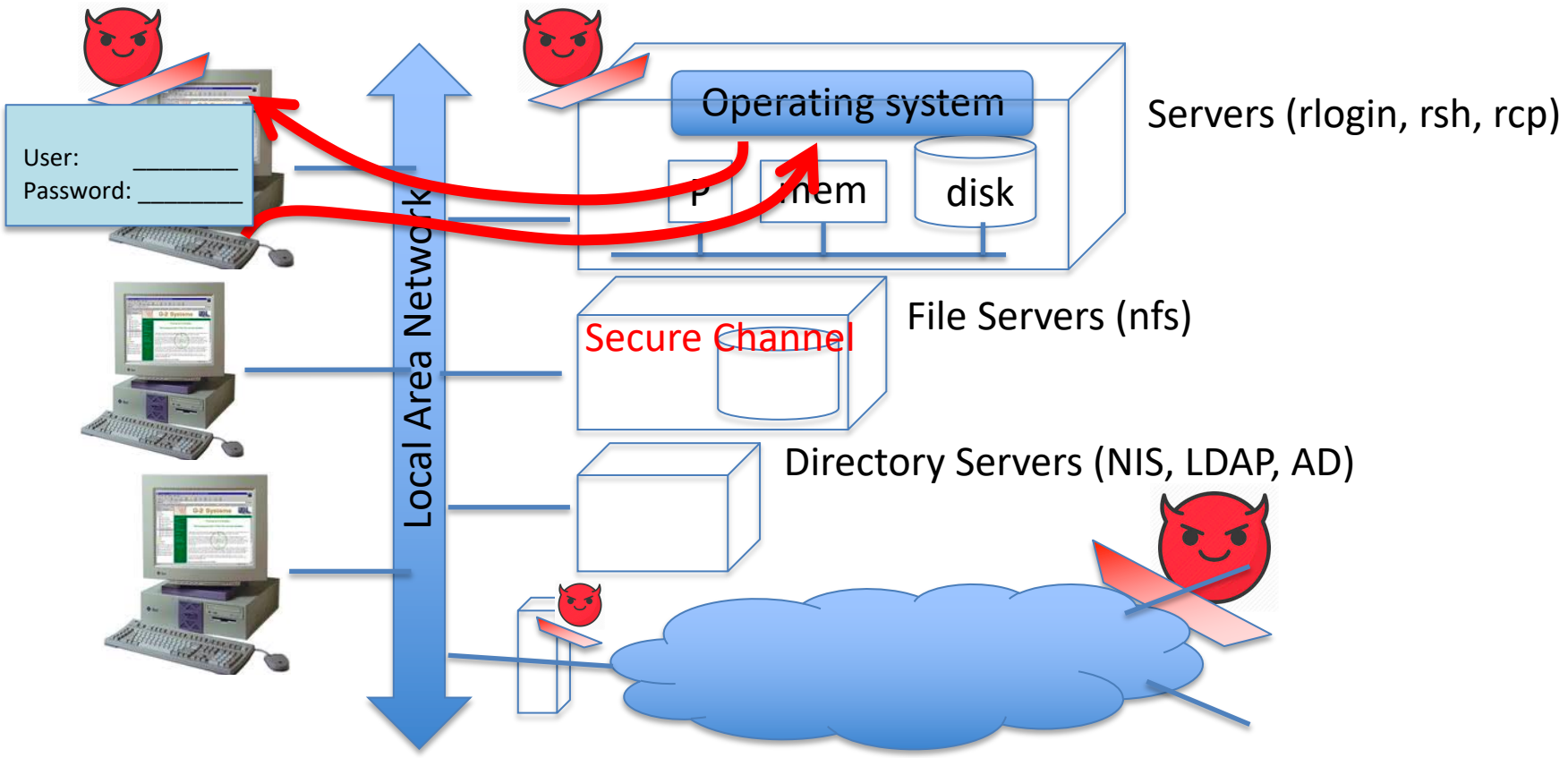
- More sophisticated (e.g., block cipher) algorithms
  - Works with a *block size* (e.g., 64 bits)
    - To encrypt a stream, can encrypt blocks separately, or link them



Symmetric Key Ciphers - DES & AES

- Data Encryption Standard (DES)
  - Developed by IBM in 1970s, standardized by NBS/NIST
  - 56-bit key (decreased from 64 bits at NSA's request)
  - Still fairly strong other than brute-forcing the key space
    - But custom hardware can crack a key in < 24 hours
  - Today many financial institutions use Triple DES
    - DES applied 3 times, with 3 keys totaling 168 bits
- Advanced Encryption Standard (AES)
  - Replacement for DES standardized in 2002
  - Key size: 128, 192 or 256 bits
  - Hardware instruction support in some processors
- How fundamentally strong are they?
  - No one knows (no proofs exist)

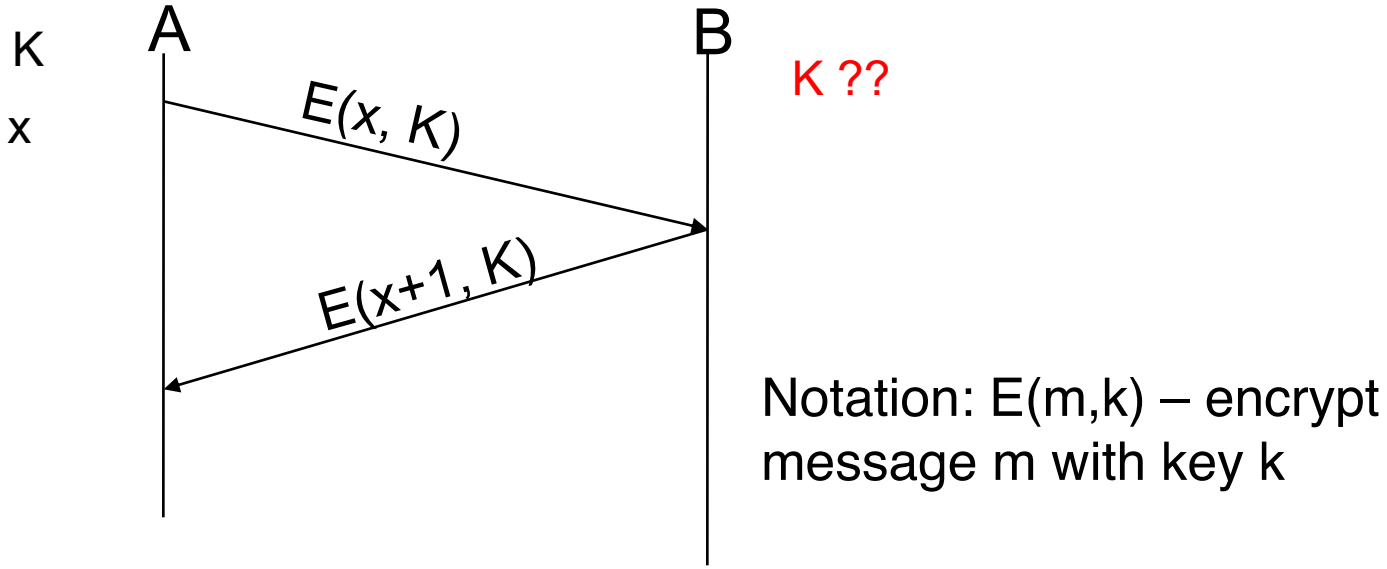
Use symmetric keys to secure this ?



- Secure Channels - Confidentiality
- Key distribution protocols
  - E.g., Kerberos
- Even if I can secure the channel, I don't want to send passwd

Authentication via Secret Key

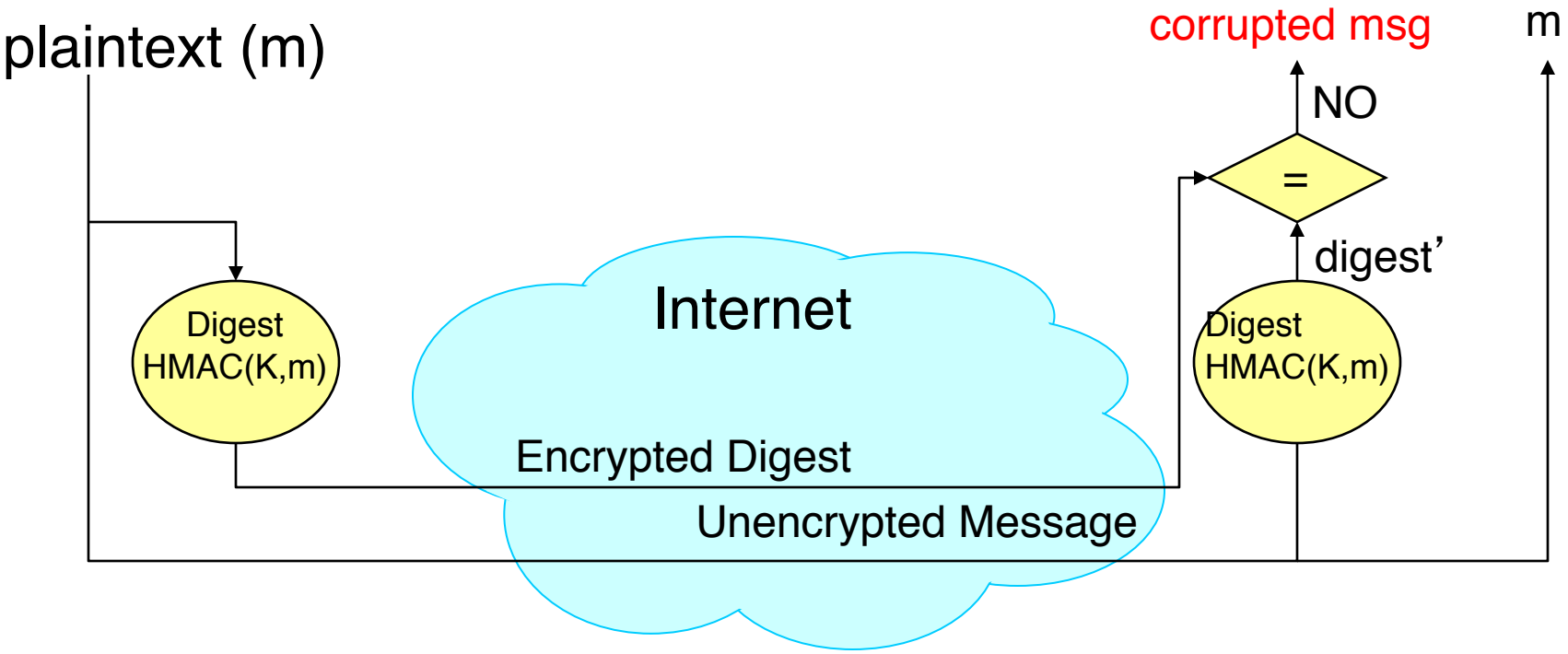
- Main idea: entity proves "identity" by decrypting a secret encrypted with its key
  - K – secret key shared only by A and B
- A can asks B to authenticate itself by decrypting a nonce, (i.e., random value) *x*, and re-encrypting incremented *x*
  - Avoid replay attacks (attacker impersonating client or server)
- *Vulnerable to tampering*



Integrity: Cryptographic Hashes

- Basic building block for integrity: *cryptographic hashing*
  - Associate hash with byte-stream, receiver verifies match
    - Assures data hasn't been modified, either accidentally – or maliciously
- Approach:
  - Sender computes a *secure digest* of message m using H(x)
    - H(x) is a publicly known *hash function*
    - Digest d = HMAC (K, m) = H (K ‖ H (K ‖ m))
    - HMAC(K, m) is a *hash-based message authentication function*
  - Send digest d and message m to receiver
  - Upon receiving m and d, receiver uses shared secret key, K, to recompute HMAC(K, m) and check result agrees with d
  - Integrity and Authenticity

Using Hashing for Integrity

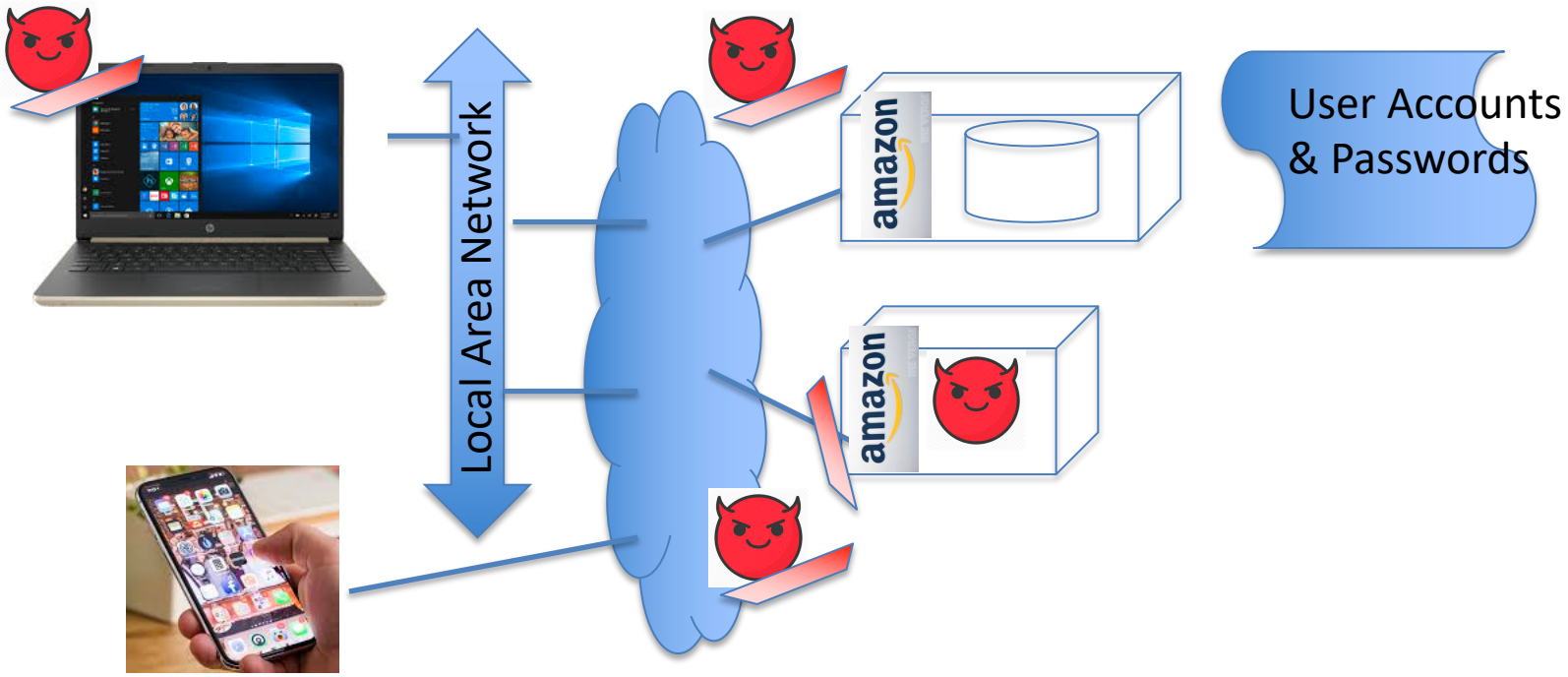


Can encrypt m for confidentiality

Standard Cryptographic Hash Functions

- MD5 (Message Digest version 5)
  - Developed in 1991 (Rivest), produces 128 bit hashes
  - Widely used (RFC 1321)
  - Broken (1996-2008): attacks that find collisions
- SHA-1 (Secure Hash Algorithm)
  - Developed in 1995 (NSA) as MD5 successor with 160 bit hashes
  - Widely used (SSL/TLS, SSH, PGP, IPSEC)
  - Broken in 2005, government use discontinued in 2010
- SHA-2 (2001)
  - Family of SHA-224, SHA-256, SHA-384, SHA-512 functions
- HMAC's are secure even with older "insecure" hash functions

No shared administration or trust …



- Web service maintains its authentication database
- Cannot send username and passwd to it
- How do you even know it is who it claims to be?

Course Evaluations: Best Practices for Students

Actually complete your course evaluations!

Make your voice heard and call attention to what worked and what didn't to improve the future experience of your peers! Course staff *do* read your responses and take action.

Go to course-evaluations.berkeley.edu to fill them out. Evaluations close May 12!

Provide constructive written feedback in addition to numeric ratings.

Written feedback gives your course staff direction when improving their course and their teaching! It may also be considered when deciding awards, promotions, and tenure.

Be candid and detailed when sharing your experiences and offer actionable suggestions!

Example: "Project 3 confused me because of <reason>. <This idea> might have helped."

If your course had TAs, review the TAs you meaningfully interacted with!

We encourage you to review any and all TAs you had for section and/or received help from in office hours!

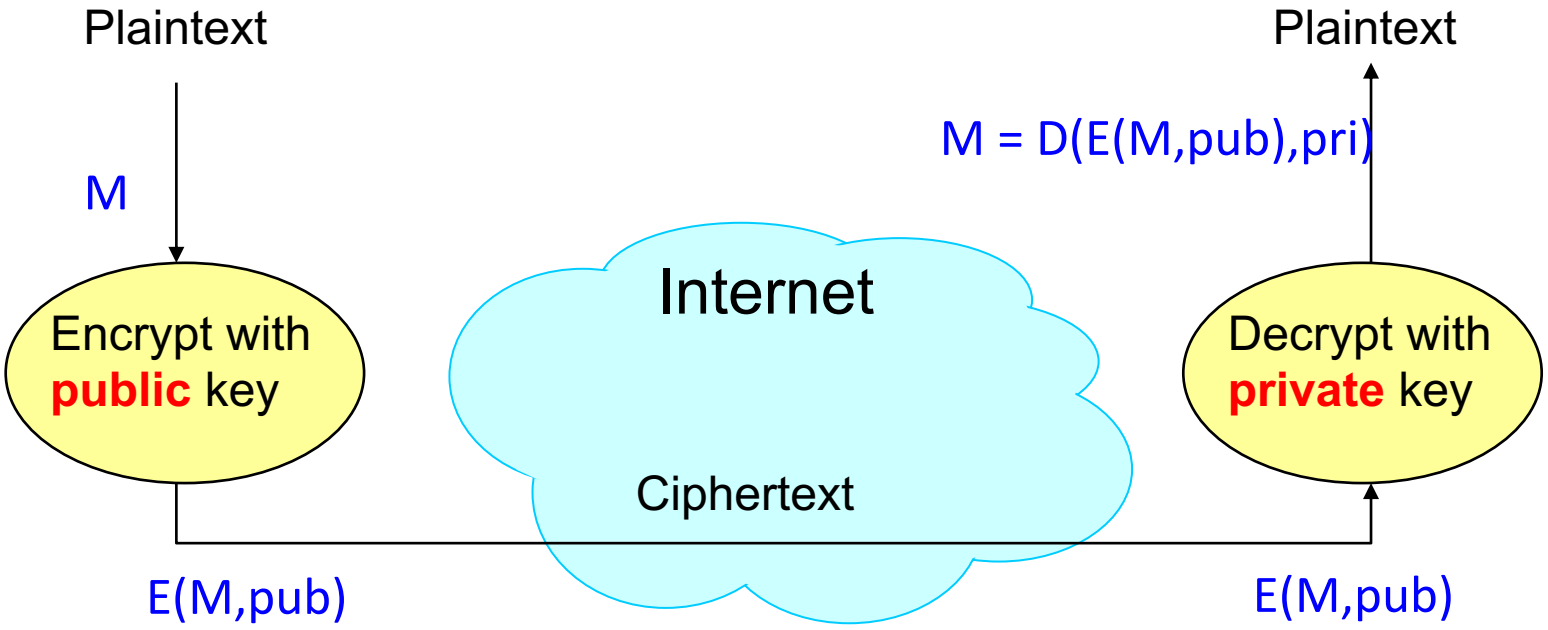
If you did not interact with a TA, **leave their section blank.** Selecting "Neutral" by default creates noise within the evaluation data and makes interpretating TA ratings more difficult.

Asymmetric Encryption *(Public Key)*

- Idea: use two *different* keys, one to encrypt (*e*) and one to decrypt (*d*)
  - A key pair
- Crucial property: knowing *e* does not give away *d*
- Therefore *e* can be public: everyone knows it!
- If Alice wants to send to Bob, she fetches Bob's public key (say from Bob's home page) and encrypts with it
  - Alice can't decrypt what she's sending to Bob …
  - … but then, neither can anyone else (except Bob)

Public Key / Asymmetric Encryption

- Sender uses receiver's public key
  - Advertised to everyone
- Receiver uses complementary private key
  - Must be kept secret



Public Key Cryptography

- Invented in the 1970s
  - *Revolutionized* cryptography
  - (Was actually invented earlier by British intelligence)

- How can we construct an encryption/decryption algorithm using a key pair with the public/private properties?
  - Answer: Number Theory

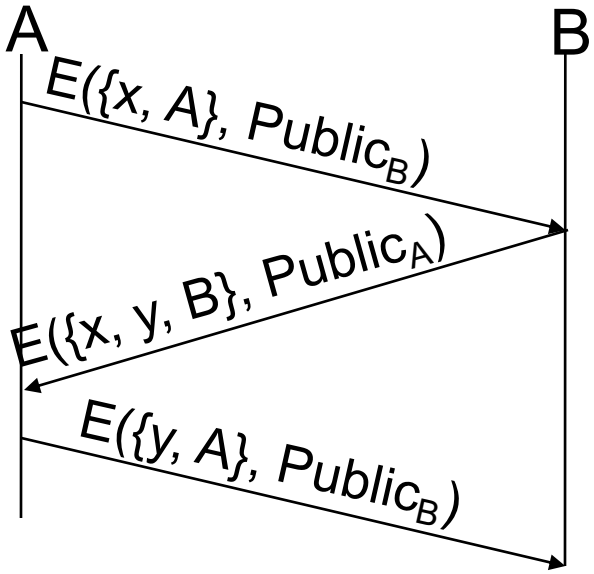
- Most fully developed approach: RSA
  - Rivest / Shamir / Adleman, 1977; RFC 3447
  - Based on modular multiplication of very large integers
  - Very widely used (e.g., ssh, SSL/TLS for `https`)

Properties of RSA

- Requires generating large, random prime numbers
  - Algorithms exist for quickly finding these (probabilistic!)
- Requires exponentiating very large numbers
  - Again, fairly fast algorithms exist
- Overall, much slower than symmetric key crypto
  - Common general strategy: use public key crypto to exchange a (short) symmetric session key
    - Use that key then with AES or such
- How difficult is recovering d, the private key?
  - Equivalent to finding prime factors of a very large number
    - Many have tried - believed to be very hard (= brute force only)
    - (Though *quantum computers* "can" do so in polynomial time!)

Simple Public Key Authentication

- Each side need only know the other side's public key
  - No secret key need be shared
- A encrypts a nonce (random num.) *x*
  - Avoid replay attacks, e.g., attacker impersonating client or server
- B proves it can recover *x*
- A can authenticate itself to B in the same way with nonce, *y*
- *Many more details to make this work securely in practice!*



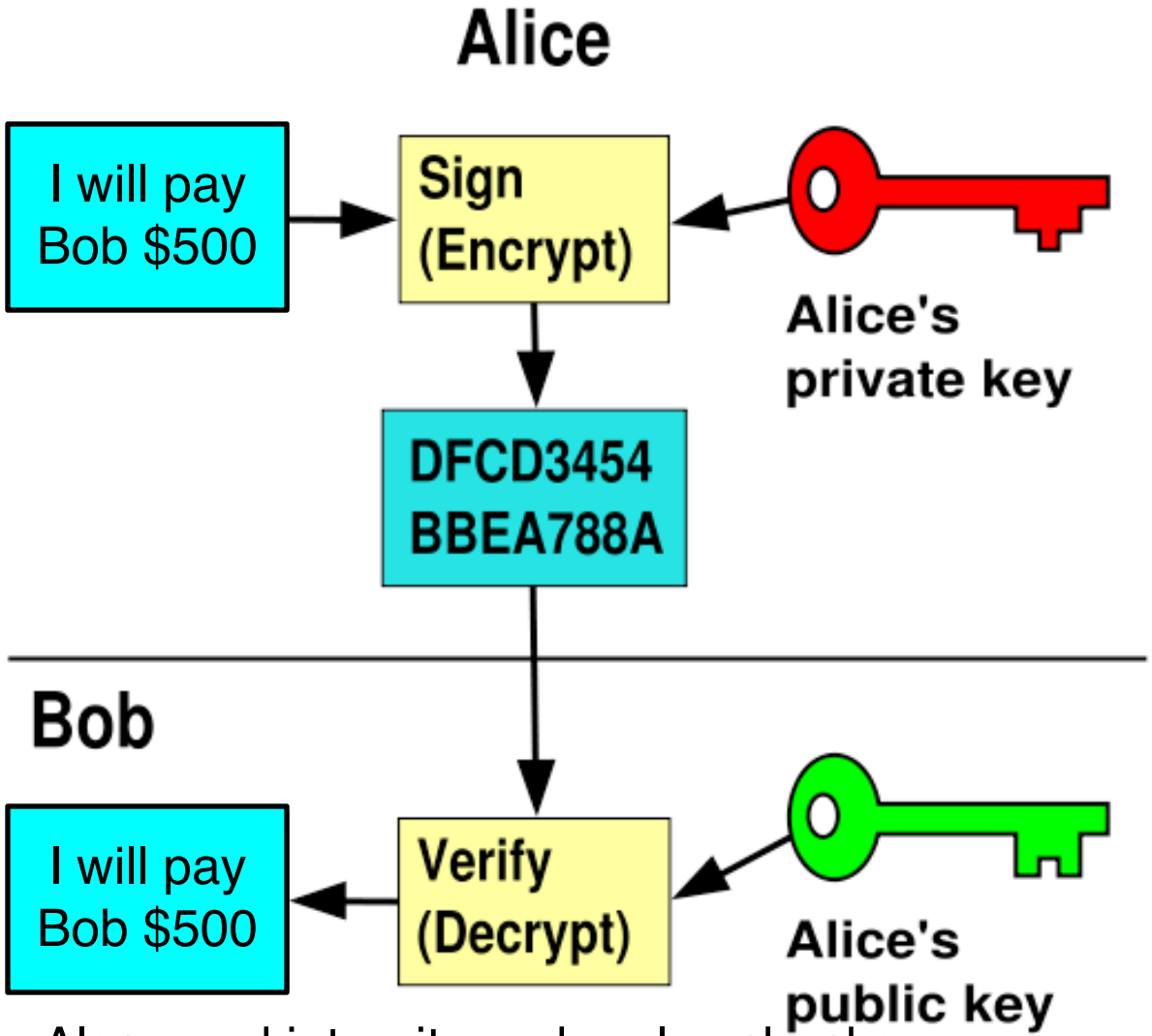
Notation: E(m,k) – encrypt message m with key k

Non-Repudiation: RSA Crypto & Signatures

- Suppose Alice has published public key K_E

- If she wishes to prove who she is, she can send a message x encrypted with her private key K_D (i.e., she sends $E(x, K_D)$)
  - Anyone knowing Alice's public key K_E can recover x, verify that Alice must have sent the message
    - It provides a signature
  - Alice can't deny it ⇒ non-repudiation

RSA Crypto & Signatures (cont'd)



Also need integrity and replay checks

Digital Certificates

- How do you know K_E is Alice.com's public key?
- Trusted authority (e.g., Verisign) signs binding between Alice.com and K_E with *its* private key $KV_{private}$
  - $C = E(\{Alice, K_E\}, KV_{private})$
  - C: *digital certificate*
- Alice: distribute her digital certificate, C
- Anyone: use trusted authority's KV_{public}, to extract Alice.com's public key from C
  - $D(C, KV_{public}) = D(E(\{Alice, K_E\}, KV_{private}), KV_{public}) = \{Alice, K_E\}$

Summary of Our Crypto Toolkit

- If we can securely distribute a key, then
  - Symmetric ciphers (e.g., AES) offer fast, presumably strong confidentiality
- Public key cryptography does away with (potentially major) problem of secure key distribution
  - But: not as computationally efficient
    - Often addressed by using public key crypto to exchange a session key
- Digital certificate binds the public key to an entity

Quiz: Cryptography

- Q1: True _ False _ Integrity requires the sender to encrypt the message
- Q2: True _ False _ Asymmetric Key Cryptography is much slower than Symmetric Key Cryptography
- Q3: True _ False _ Encrypting a nonce (random number) avoids replay attacks
- Q4: True _ False _ Confidentiality guarantees data integrity

Quiz: Cryptography

- Q1: True _ False X Integrity requires the sender to encrypt the message
- Q2: True X False _ Asymmetric Key Cryptography is much slower than Symmetric Key Cryptography
- Q3: True X False _ Encrypting a nonce (random number) avoids replay attacks
- Q4: True _ False X Confidentiality guarantees data integrity

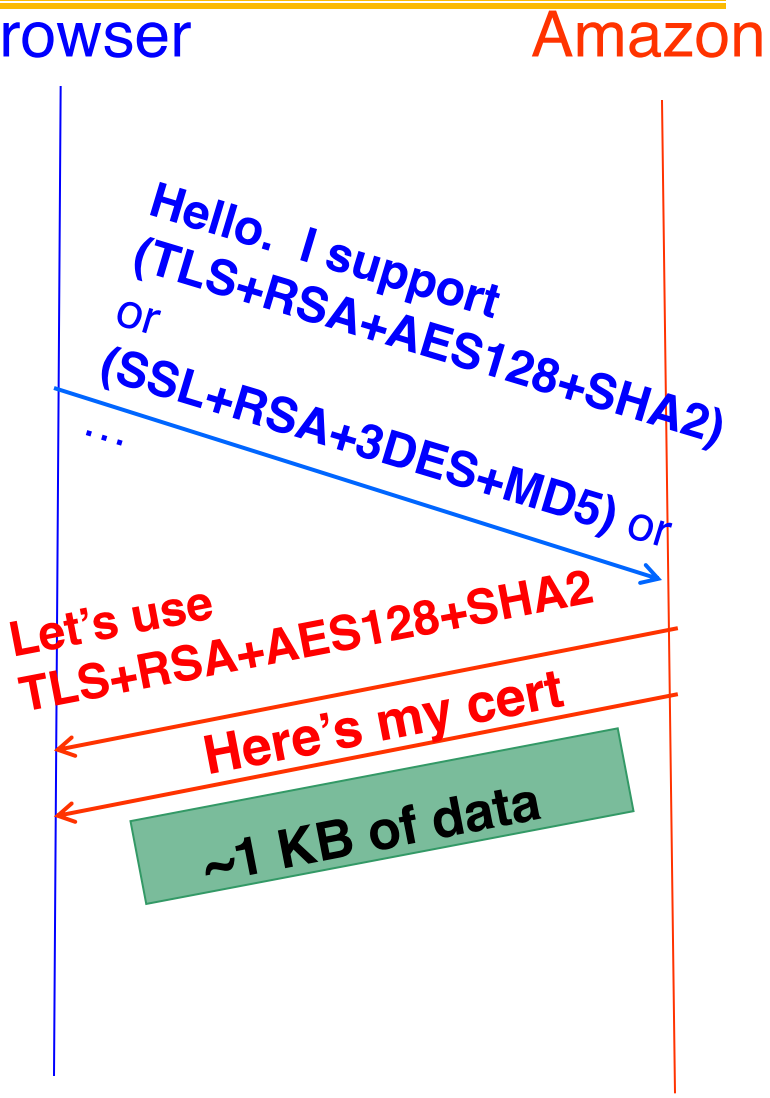
Putting It All Together - HTTPS

- What happens when you click on https://www.amazon.com?

- https = "Use HTTP over SSL/TLS"
  - SSL = Secure Socket Layer
  - TLS = Transport Layer Security
    - Successor to SSL
  - Provides security layer (authentication, encryption) on top of TCP
    - Fairly transparent to applications

HTTPS Connection (SSL/TLS)

- Browser (client) connects via TCP to Amazon's HTTPS server
- Client sends over list of crypto protocols it supports
- Server picks protocols to use for this session
- Server sends over its certificate
- (all of this is in the clear)



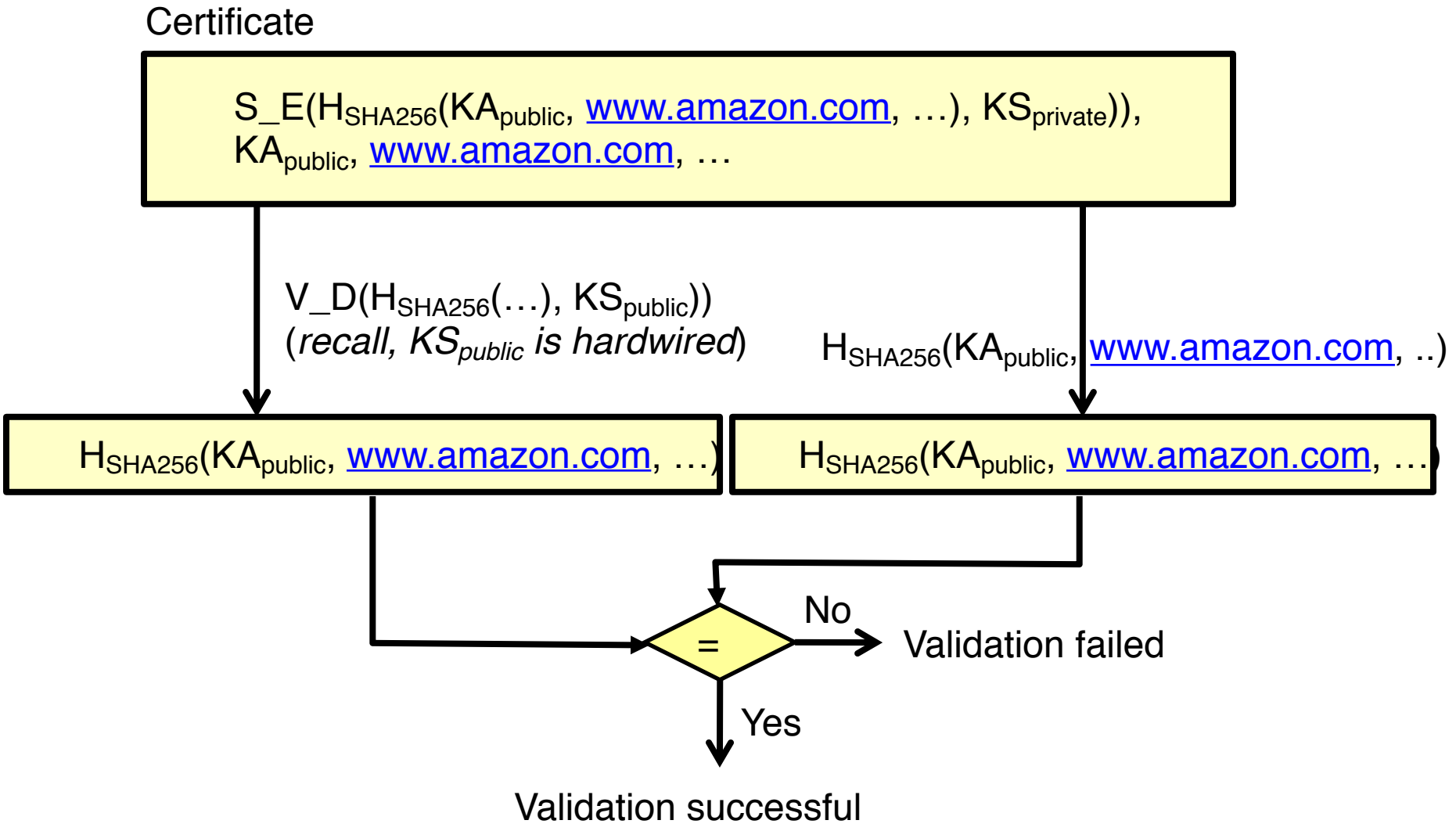
Inside the Server's Certificate

- Name associated with cert (e.g., Amazon)
- Amazon's RSA public key
- A bunch of auxiliary info (physical address, type of cert, validity time period)
- Name of certificate's signatory (who signed it)
- A public-key signature of a hash (SHA-256) of all this
  - Constructed using the signatory's private RSA key, i.e.,
  - Cert = {(KA_{public}, www.amazon.com, …),
    $E(H_{SHA256}(KA_{public}$, www.amazon.com, …), $KS_{private})$}
    - KA_{public}: Amazon's public key
    - $KS_{private}$: signatory (certificate authority) private key
- …

Validating Amazon's Identity

- How does the browser authenticate certificate signatory?
  - Certificates of several certificate authorities (e.g., Verisign) are hardwired into the browser (or OS)
- If can't find cert, warn user that site has not been verified
  - And may ask whether to continue
  - Note, can still proceed, just without authentication
- Browser uses public key in signatory's cert to decrypt signature
  - Compares with its own SHA-256 hash of Amazon's cert
- Assuming signature matches, now have high confidence it's indeed Amazon …
  - … assuming signatory is trustworthy
  - *DigiNotar CA breach (July-Sept 2011): Google, Yahoo!, Mozilla, Tor project, Wordpress, … (531 bogus certificates!!)*

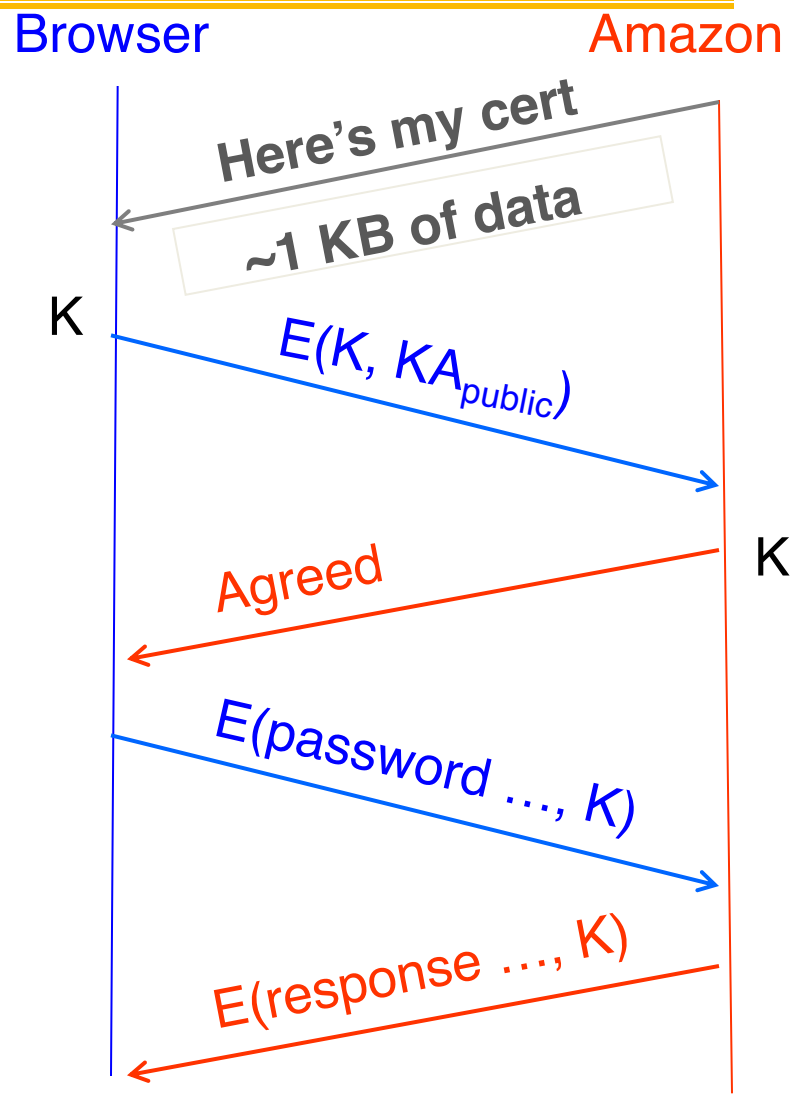
Certificate Validation



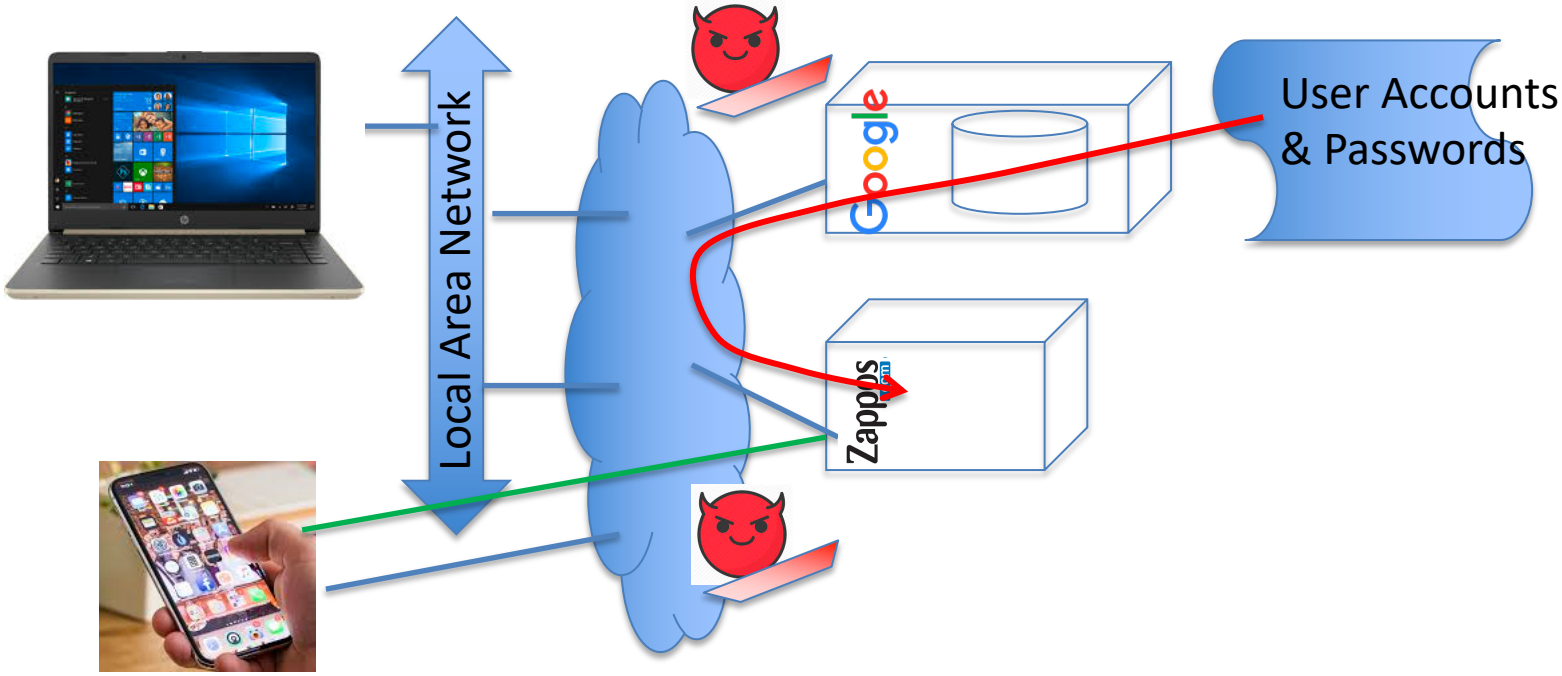
Can also validate using peer approach: https://www.eff.org/observatory

HTTPS Connection (SSL/TLS) cont'd

- Browser constructs a random *session key* K used for data communication
  - Private key for bulk crypto
- Browser encrypts K using Amazon's public key
- Browser sends E(K, KA_{public}) to server
- Browser displays 🔒
- All subsequent comm. encrypted w/ symmetric cipher (e.g., AES128) using key K
  - E.g., client can authenticate using a password

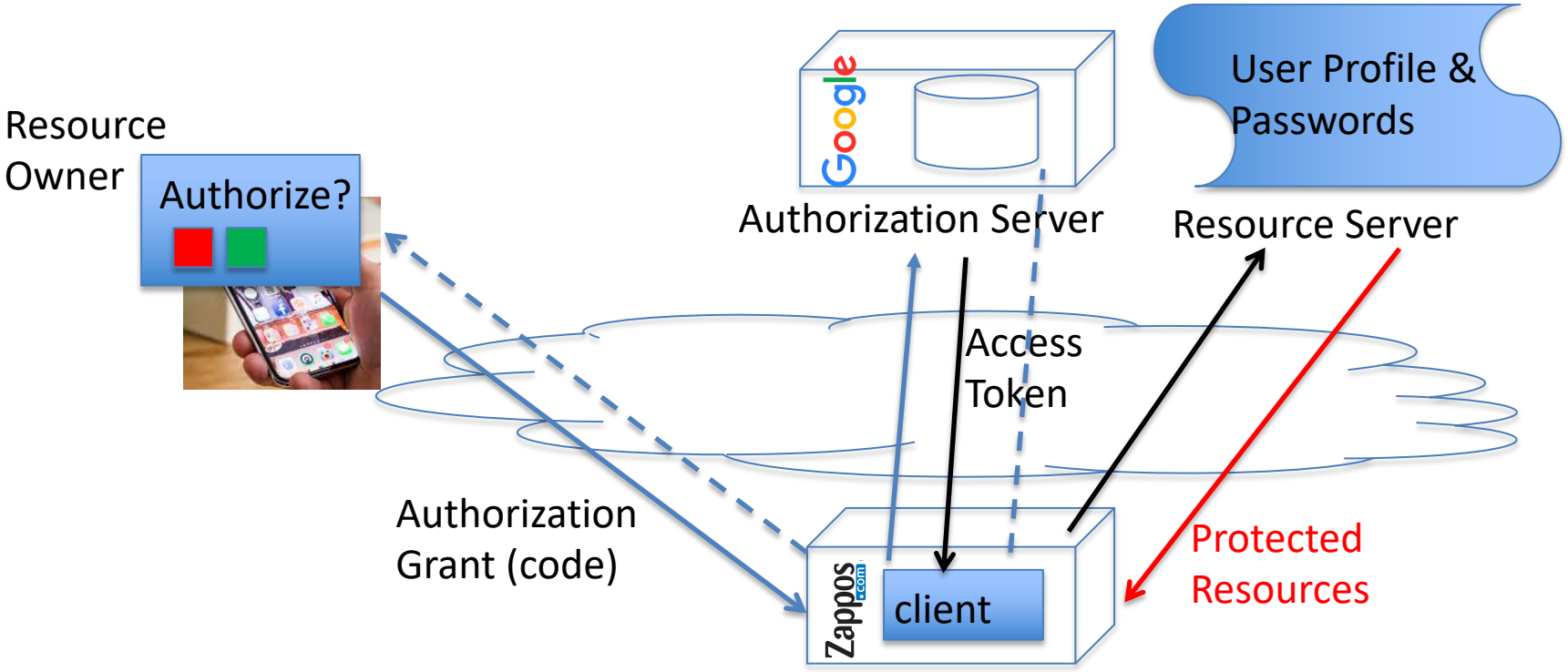


Services delegate authentication to other services



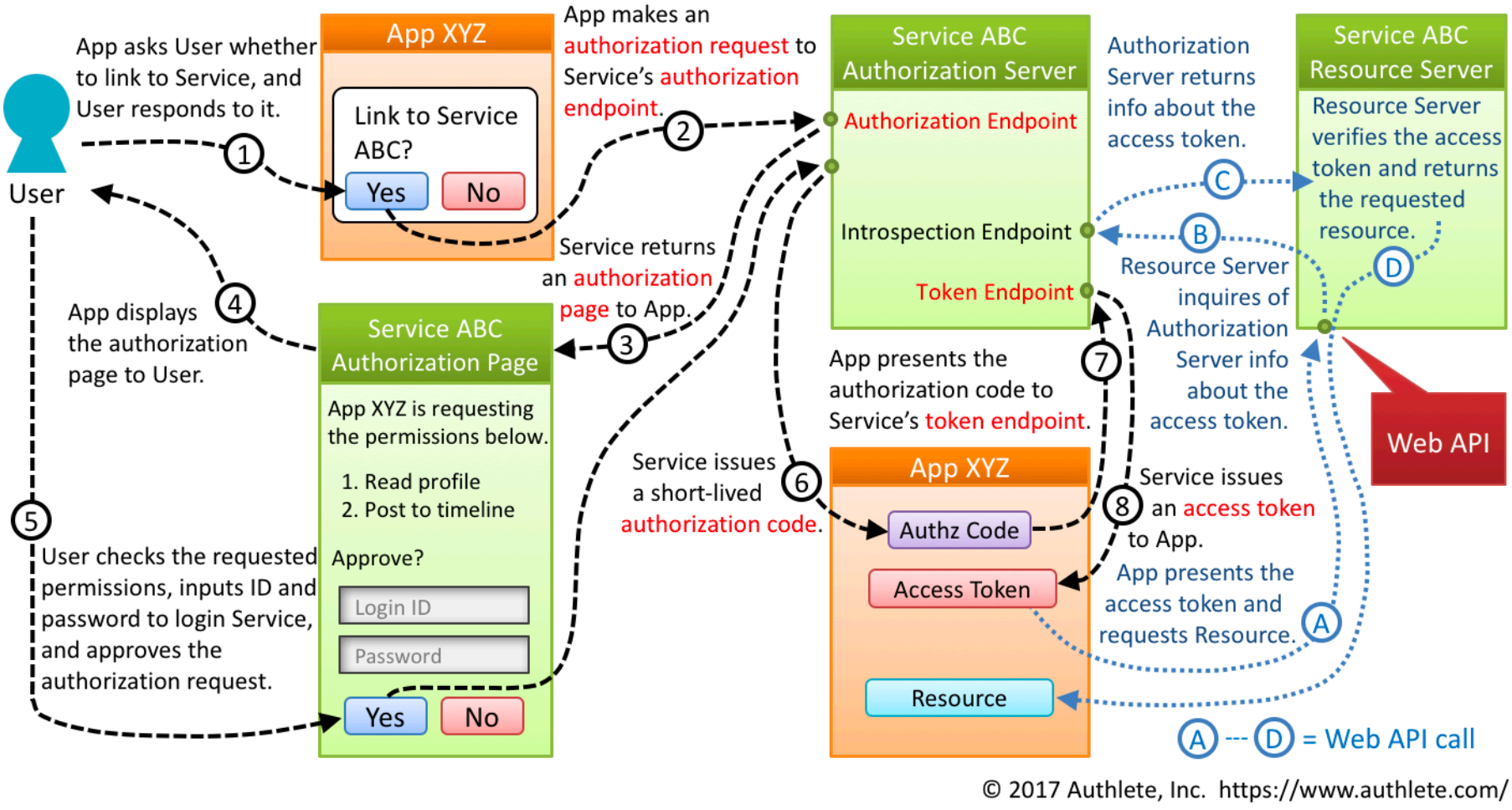
- Rather than every service maintaining its own dedicated identity / authentication
- It might delegate that to a widely used service
- Principal authorizes its authentication provider
- OAUTH, OAUTH 2

OAUTH2 – in concept



- Client app pre-registers with auth server, obtaining credentials
- Resource owner gives it permission to utilize auth server, via the auth server
- Client app obtains an access token from auth server on grant
- Uses that token to access protected resources

Authorization Code Flow (RFC 6749, 4.1)



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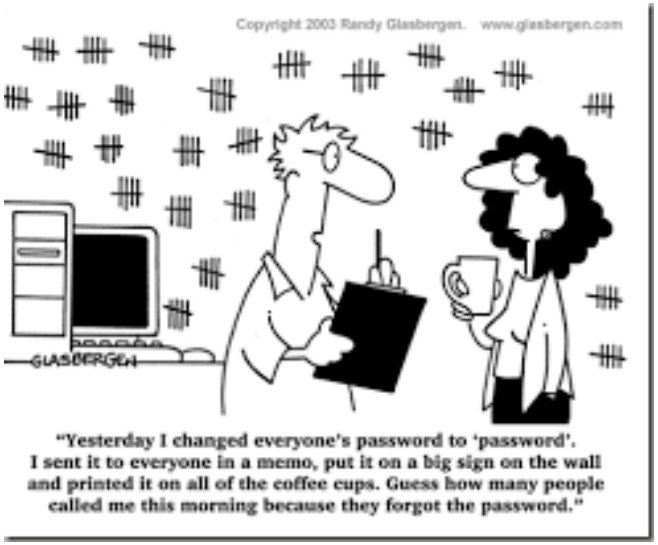
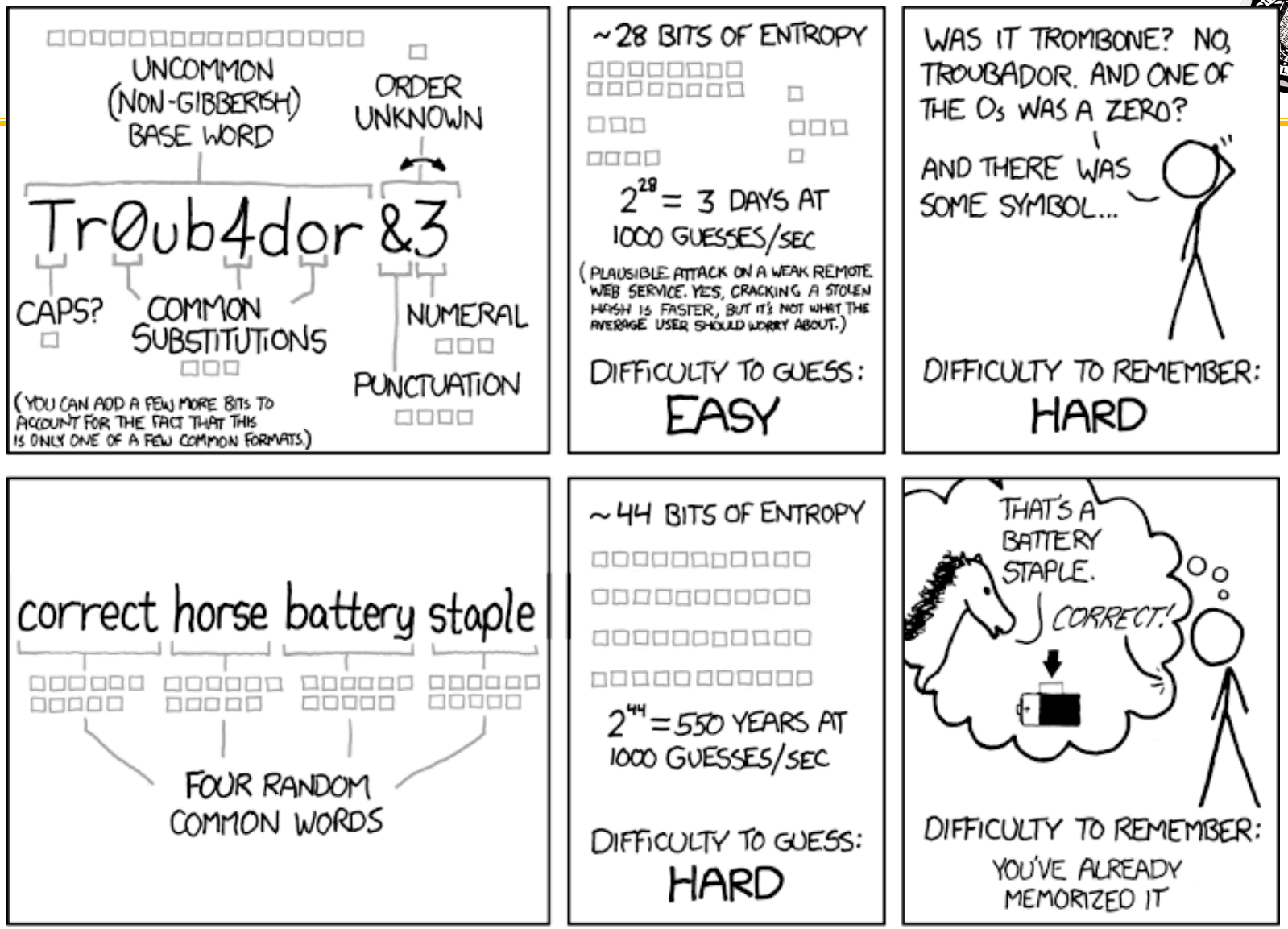
The Human Part





THROUGH 20 YEARS OF EFFORT, WE'VE SUCCESSFULLY TRAINED EVERYONE TO USE PASSWORDS THAT ARE HARD FOR HUMANS TO REMEMBER, BUT EASY FOR COMPUTERS TO GUESS. https://xkcd.com/936/

Passwords: How easy to guess?

- Three common ways of compromising passwords
- Password Guessing:
  - Often obvious passwords like birthday, favorite color, girlfriend's name, etc…
  - Trivia question 1: what is the most popular password?
  - Trivia question 2: what is the next most popular password?
  - Answer: (from 32 million stolen passwords– Rockyou 2010)http://www.nytimes.com/2010/01/21/technology/21password.html
- Dictionary Attack (against stolen encrypted list):
  - Work way through dictionary and compare encrypted version of dictionary words with entries in `/etc/passwd`
  - http://www.skullsecurity.org/wiki/index.php/Passwords
- Dumpster Diving:
  - Find pieces of paper with passwords written on them
  - (Also used to get social-security numbers, etc.)

Passwords: How easy to guess? (cont'd)

- Paradox:
  - Short passwords are easy to crack
  - Long ones, people write down!

- Technology means we have to use longer passwords
  - UNIX initially required lowercase, 5-letter passwords: total of 26^5=10million passwords
    - In 1975, 10ms to check a password→1 day to crack
    - In 2005, 0.01μs to check a password→0.1 seconds to crack
  - Takes less time to check for all words in the dictionary!

Passwords: Making harder to crack

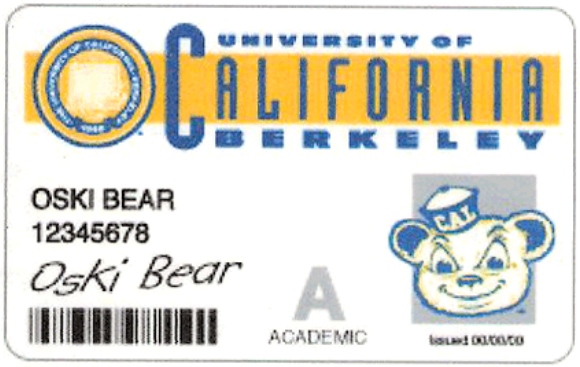
- Can't make it impossible to crack, but can make it harder
- Technique 1: Extend everyone's password with a random number ("Salt" – stored in UNIX password file)
  - Early UNIX added 12-bit "salt" making dictionary attacks 4096x harder
  - Without salt, can pre-compute hashes of all dictionary words and store "rainbow tables" on a single hard drive
- By 2005, even 12-bit salts were insufficient (use an array of hardrives to store
  - Modern salts are 48-128 bits

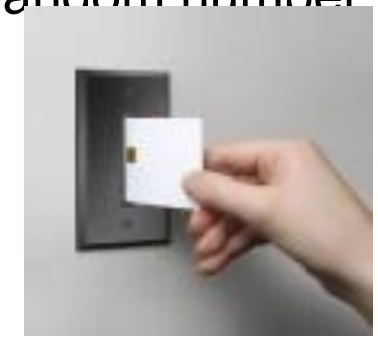
Passwords: Making harder to crack (cont'd)

- Technique 2: Require more complex passwords
  - Make people use at least 8-character passwords with upper-case, lower-case, and numbers
    - $70^8 = 6 \times 10^{14}$ = 6million seconds = 69 days@0.01µs/check
  - Unfortunately, people still pick common patterns
    - e.g., Capitalize first letter of common word, add one digit
- Technique 3: Delay checking of passwords
  - If attacker doesn't have access to `/etc/passwd`, delay every remote login attempt by 1 second
  - Makes it infeasible for rapid-fire dictionary attack

Passwords: Making harder to crack (cont'd)

- Technique 4: Assign very long passwords/passphrases
  - Can have more entropy (randomness→harder to crack)
  - Embed password in a smart card (or ATM card)
    - Requires physical theft to steal password
    - Can require PIN from user before authenticates self
  - Better: have smartcard or smartphone generate pseudorandom number as a password
    - Client and server share initial seed
    - Each second/login attempt advances random number

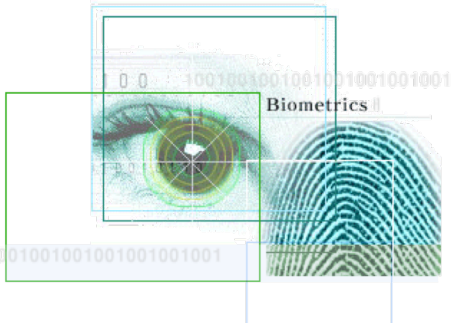




Passwords: Making harder to crack (cont'd)

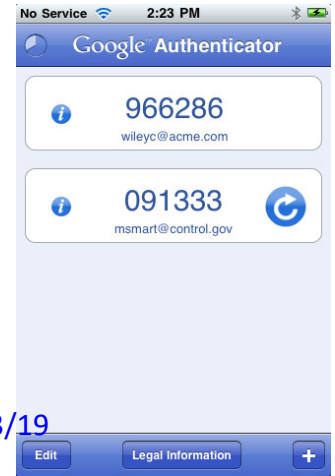
- Technique 5: "Zero-Knowledge Proof"
  - Require a series of challenge-response questions
    - Distribute secret algorithm to user
    - Server presents number; user computes something from number; returns answer to server; server never asks same "question" twice
  - Often performed by smartcard plugged into system

- Technique 6: Replace password with Biometrics
  - Use of one or more intrinsic physical or behavioral traits to identify someone
  - Examples: fingerprint reader, palm reader, retinal scan



Two-Factor Authentication

- Authentication typically involves:
  - Something the user knows (e.g. password, friend's face)
  - Something the user has (ATM card, fob, dongle)
  - Something the user is (face, voice, fingerprints, bio-signs)
- Two-factor authentication involves two of these factors
  - Smartphone app provides a pseudorandom PIN for password
  - Credit Card – Chip and PIN



Conclusion

- Distributed identity: Use cryptography
- Symmetrical (or Private Key) Encryption
  - Single Key used to encode and decode
  - Introduces key-distribution problem
- Public-Key Encryption
  - Two keys: a public key and a private key
  - Slower than private key, but simplifies key-distribution
- Secure Hash Function
  - Used to summarize data
  - Hard to find another block of data with same hash
- Passwords
  - Encrypt *and salt* them to help hide them
  - Force them to be longer/not amenable to dictionary attack
  - Use zero-knowledge request-response techniques

Additional Notes on Public Key Cryptography (Not required for Course or Exams)

Generating Public and Private Keys

- Choose two large prime numbers p and q (>1500 256 bit long) and multiply them: $n = p*q$
- Chose encryption key e such that e and $(p-1)*(q-1)$ are relatively prime
- Compute decryption key d as

  $d = e^{-1} \bmod ((p-1)*(q-1))$

  (equivalent to $d*e = 1 \bmod ((p-1)*(q-1))$)

- Public key consist of pair (n, e)
- Private key consists of pair (d, n)

RSA Encryption and Decryption

- Encryption of message block *m*:
  - $c = m^e \bmod n$
- Decryption of ciphertext *c*:
  - $m = c^d \bmod n$

Example (1/2)

- Choose p = 7 and q = 11 → n = p*q = 77
- Compute encryption key e: (p-1)*(q-1) = 6*10 = 60 → chose e = 13 (13 and 60 are relatively prime numbers)
- Compute decryption key d such that 13*d = 1 mod 60 → d = 37 (37*13 = 481)

Example (2/2)

- n = 77; e = 13; d = 37
- Send message block m = 7
- Encryption: $c = m^e \bmod n = 7^{13} \bmod 77 = 35$
- Decryption: $m = c^d \bmod n = 35^{37} \bmod 77 = 7$

Properties

- Confidentiality
- A receiver A computes n, e, d, and sends out (n, e)
  - Everyone who wants to send a message to A uses (n, e) to encrypt it
- How difficult is to recover d ? (Someone that can do this can decrypt any message sent to A!)
- Recall that

$$d = e^{-1} \bmod ((p-1)*(q-1))$$

- So to find d, you need to find primes factors p and q
  - This is provable hard