Administrivia

- **No text book for this class**
  - We will mostly be discussing papers
  - Handout in first lecture is draft chapter of MIT textbook
  - Provides some background, but *far from perfect*
  - Will maybe put up a better version later in semester
- **Please join the class mailing list**
  - Link to join on class home page
    `http://www.scs.cs.nyu.edu/css/`

Errata

- **I was sloppy with term *authorization* last class**
  - Is authorization granting you access to a file?
  - Or is authorization the OS checking you have permission when you access the file?
- **From now on, authorization will mean the former**
  - Corresponds more closely to English usage
- **Use term *mediation* to mean check authorization**
- **Examples:**
  - NYU *authorizes* you to use library by issuing you ID
  - Bobst turnstiles *mediate* access by checking IDs

Digital signatures

- **Three (randomized) algorithms:**
  - *Generate* – $G(1^k) \rightarrow K, K^{-1}$
  - *Sign* – $S\left(K^{-1}, m\right) \rightarrow \{m\}_{K^{-1}}$
  - *Verify* – $V\left(K, \{m\}_{K^{-1}}, m\right) \rightarrow \{\mathbf{true}, \mathbf{false}\}$
- **Provides integrity, like a MAC**
  - Cannot produce valid $\langle m, \{m\}_{K^{-1}} \rangle$ pair without K^{-1}
- **Many keys support both signing & encryption**
  - But Encrypt/Decrypt and Sign/Verify different algorithms!
  - Common error: Sign by "encrypting" with private key

Digital signature security

- **Want signatures to be secure for all applications**
  - Analogous to strength of encryption definition
- **Existential unforgeability against chosen message attack $\Longrightarrow$ attacker has negligible chance of winning this game:**
  - Attacker asks you to sign $m_0, m_1, \ldots, m_n$
  - Attacker gets valid s_i after request for m_i
  - Attacker outputs (m', s'), where $m' \notin \{m_i\}$ and $\mathit{Verify}(K, m', s') = \mathbf{true}$

Example: ElGamal signatures

- **Key generation:**
  - Chose large prime p, generator g of $\mathbf{Z}_p^*$ (p, g can be global)
  - Select x such that $1 \leq x \leq p-2$, compute $y \leftarrow g^x \bmod p$
  - Public key is (p, g, y), private key is (p, g, x)
- **Signature of m is (r, s), computed as follows:**
  - Chose random k s.t. $1 \leq k \leq p-2$ and $k^{-1} \bmod p-1$ exists
  - Set $r \leftarrow g^k \bmod p$, $s \leftarrow k^{-1}\left(H(m) - xr\right) \bmod (p-1)$
- **Verification:**
  - Sanity check: $1 \leq r \leq p-1$
  - Verify: $y^r r^s \stackrel{?}{\equiv} g^{H(m)} \pmod p$
  - $y^r r^s = \left(g^{xr}\right)\left(g^{ks}\right) = g^{xr+ks} = g^{xr+k\cdot k^{-1}(H(m)-xr)} = g^{H(m)}$

Cost of cryptographic operations

Operation	msec
Encrypt	0.18
Decrypt	6.60
Sign	6.71
Verify	0.03

[1,280-bit Rabin-Williams keys on 3 GHz Pentium IV]

- **Cost of public key algorithms significant**
  - Encryption only on small messages (< size of key)
  - Signature cost relatively insensitive to message size
- **In contrast, symmetric algorithms much cheaper**
  - Symmetric can encrypt+MAC faster than 100Mbit/sec LAN

Hybrid schemes

- **Use public key to encrypt symmetric key**
  - Send message symmetrically encrypted: $\{\text{msg}\}_{K_S}, \{K_S\}_{K_P}$
- **Use PK to negotiate secret session key**
  - E.g., Client sends server $\{K_1, K_2, K_3, K_4\}_{K_P}$
  - Client sends server: $\{\{m_1\}_{K_1}, \text{MAC}(K_2, \{m_1\}_{K_1})\}$
  - Server sends client: $\{\{m_2\}_{K_3}, \text{MAC}(K_4, \{m_2\}_{K_3})\}$
- **Often want mutual authentication (client & server)**
  - Or more complex, user(s), client, & server

Passwords

- **Many systems require passwords for access**
- **Example: Tenex directories require passwords**
  - Stored in cleartext by the system
- `connect` **system call gets access to directories**
  - Passes in pointer to string
  - OS performs the following check:

```
for (i = 0; i <= strlen (directoryPassword); i++)
    if (directoryPassword[i] != passwordArgument) {
        sleep (3);
        return EACCES;
    }
return 0;
```

Weaknesses

- **Bad: Vulnerability of keeping plaintext passwords**
  - By compromising the system, can all passwords
- **Worse: Can guess password in linear time!**
  - Place first character of password as last byte on VM page
  - Make sure the next page is unmapped
  - Try all first letters, one by one
  - Got a page fault? Must have correct first letter
  - Repeat for second character of password, etc.

Unix hashed passwords

- **Store one-way function of password**
  - Only hashes first 8 characters
  - Encrypt 0s 25 times with password as key
  - Key generally hard to recover from ciphertext
  - So put hashed password in world-readable `/etc/passwd`
  - To validate password, hash it and compare to stored hash
- **Hash function "salted" with 12 extra bits**
  - Prevent attacker from building dictionary of hashes of common passwords
  - Permute the hash function based on 12-bit seed
  - Prepend seed to hashed password for use in verification

Weaknesses

- **Off-line password guessing attacks**
  - Attacker gets password file, guesses passwords at home
  - Computationally expensive, but undetectable by victims
- **Fails to account for hardware & software improvements**
  - DES crypt on 1977 VAX-11/780: 4 crypts/sec
  - Bitsliced implementation on 600 MHz alpha: 214,000 cr/sec
  - But users don't chose better passwords now than in 1977!
- **Server still gets plaintext password at login**
  - Attacker or server operator can modify login to record it
  - But users often use same password on different systems

Design hints for systems with passwords

- **Any algorithm that uses passwords should:**
  - Take a salt as input (prevent hash dictionaries)
  - Take a cost parameter as input
    Administrators need to increase hashing cost as hardware gets faster!
- **Bad examples: PGP & ssh private keys**
  - Stored in user's home directory, encrypted with password
  - Given encrypted private key, can guess password off-line
  - Cost of guess even cheaper than password crypt!
- **Good example: OpenBSD/FreeBSD bcrypt**
  - Hashing password is exponential in cost parameter
  - Cost goes in hashed password along with salt

Network Passwords

- **Many systems grant access through a password**
- **How to implement? Example:**
  - Server stores user's password (or hash)
  - Client connects to server, sends username, password
  - Server compares password to stored version
  - Grants access if they match
- **Is this a good approach?**

Weaknesses

- **How do you know you are talking only to server**
  - Attacker might be eavesdropping on Ethernet
  - Attacker might mess with DNS (or IP routing) so you talk to wrong machine
- **Eavesdropper will just read your password off the network**
- **Server knows your plaintext password**
  - Or at least sees it at login time, even if stores hash
  - Bad because people re-use passwords on multiple machines

s/key password authentication

- **Goal: Protect against passive eavesdroppers**
  - Also: Minimize harm of bad clients (e.g., public terminals)
- **Idea: One time passwords, not valid after snooped**
- **Algorithm takes user's real password, p, a random "salt" s, and server machine name m**
  - First one time password is $H^{(100)}(p, m, s)$ (for one way hash H)
  - Next password is $H^{(99)}(p, m, s)$, etc.
  - After 99 logins, must change salt or password
- **Benefit: Very convenient**
  - Carry list of one-time passwords, calculate on palm pilot

Weaknesses

- **Vulnerable to network attackers**
  - Attacker impersonates server
  - Re-sends one-time password to real server
- **Vulnerable to off-line password guessing**
  - Attacker sees s and $H^{(n)}(p, m, s)$
  - Can verify guesses of p off-line – check against dictionary of common passwords
  - H not very expensive (should be $H^{(n)}(G(p, m, s))$ for expensive G—or maybe users should crank n)
- **Bad client can compromise session**
  - Before logout, can insert command to create back door:
    `echo 1024 35 145...3 badguy >> .ssh/authorized_keys`

Password-derived public keys

- **Derive public key from user's password**
  - E.g., use password as seed for pseudo-random generator
  - Client can regenerate private key given password
- **Server stores public key for each user**
- **Use public key authentication, E.g.:**
  - $S \rightarrow C : N_S$
  - $C \rightarrow S : K_u, \{C, S, K_S, u, \text{session}, N_S\}_{K_u^{-1}}$
  - K_S is server public key, used to authenticate server
  - Server checks sig, looks up pubkey K_u for credentials

Weaknesses

- **No salt**
  - Users with same password will have same public key
- **No cost parameter**
  - Can't take too long to log in
  - But over time generating key will get faster
- **Public key is just like password hash**
  - Eavesdropper will see key, can mount off-line attack
- **No authentication of server to user**
  - W/o accessing server, attacker can pretend server is giving bad answers

MAC of server public key

- **User chooses password p. Server stores:**
  - $h \leftarrow H(p, \text{servername})$ (where H is hash with parameterizable cost)
- **Server authenticates its public key to user with secret h**
  - $S \rightarrow C : \text{MAC}(h, K_S)$
  - Client can establish secure channel using K_S

Weaknesses

- **Still vulnerable to offline password guessing**
- **No forward secrecy**
  - Attacker can record encrypted communications
  - One year later, breaks into server, gets private key
  - Can now decrypt last year's messages!

Secure password protocols

- **Purpose of secure password protocol:**
  - Generate strong shared secret from user-chosen password
  - Use secret as key for mutually authenticated session
- **Goals of the SRP protocol**
  - Network attacker should be unable learn anything that will allow an off-line guessing attack
  - Forward secrecy
  - Server knows nothing plaintext-equivalent
- **Warning: SRP has not been proven correct**
  - No known bugs in SRP, but provably correct protocols exist
  - What follows is an *informal* argument about why SRP might be secure

Background: Diffie-Hellman key exchange

- **An unauthenticated key exchange protocol**
  - Provides forward secrecy against a passive adversary
- **The discrete log problem:**
  - Let p be a prime and g a generator of $\mathbf{Z}_p^*$
  - Given $x \in \mathbf{Z}_{p-1}$, easy to compute g^x from x, inverse hard
- **Diffie-Hellman protocol, given g and p**
  - A picks random x, sends B g^x
  - B picks random y, sends A g^y
  - A and B use $H(g^{xy})$ as session key
- **Note: Breaking DH may be easier than discrete log**

SRP protocol

- **User knows** p**, Server knows** $s, g^{H(s,p)}$
- **Get parameters.** $U \rightarrow S : U$**;** $S \rightarrow U : s, N, g$
- **User picks** a**.** $U \rightarrow S : U, A = g^a$
- **Server picks** b, u**.** $S \rightarrow U : s, B = 3g^{H(s,p)} + g^b, u$
- **User computes:** $K = H\left(\left(g^b\right)^{(a+uH(s,p))}\right)$
- **Server computes:** $K = H\left(g^a\left(g^{H(s,p)}\right)^u\right)^b$
- **In either case:** $K = H\left(g^{ab}g^{buH(s,p)}\right)$
- **Verify:** $U \rightarrow S : m_1 = H(A, B, K)$**;**
  $S \rightarrow U : H(A, m_1, K)$

Informal analysis

- **No obvious way for U to get K without p**
- **S doesn't know p**
  - Even if S's secret $g^{H(s,p)}$ stolen, thief can't impersonate user without mounting off-line guessing attack
- **No obvious way to mount off-line guessing attack**
  - Suppose attacker impersonates user
    Will know a, s, u, $3g^{H(s,p)} + g^b$, but not $H(g^{ab} g^{buH(s,p)})$
    No obvious way to pass verify step
  - Suppose attacker impersonates server and even learns K
    Will know s, B, g^a, u, and $H\left(\left(B - 3g^{H(s,p)}\right)^{a+uH(s,p)}\right)$
    No obvious way to validate guess of p

Secure password protocols in practice

- **Passwords are sufficient for mutual authentication**
  - A distributed system in which a user types a password should never be susceptible to a man in the middle attack!
  - If user establishes a password in person, no need for PKI to contact server
- **Consider adding cost parameter c to algorithms**
  - For example hash password 2^c times
  - $U \rightarrow S : U, g^a$
  - $S \rightarrow U : s, c, g^{H^{2^c}(s,p)} + g^b, u$

Stretch break

SSL/TLS Overview

- **SSL offers security for HTTP protocol**
- **Authentication of server to client**
- **Optional authentication of client to server**
  - Incompatibly implemented in different browsers
  - CA infrastructure not in widespread use
- **Confidentiality of communications**
- **Integrity protection of communications**

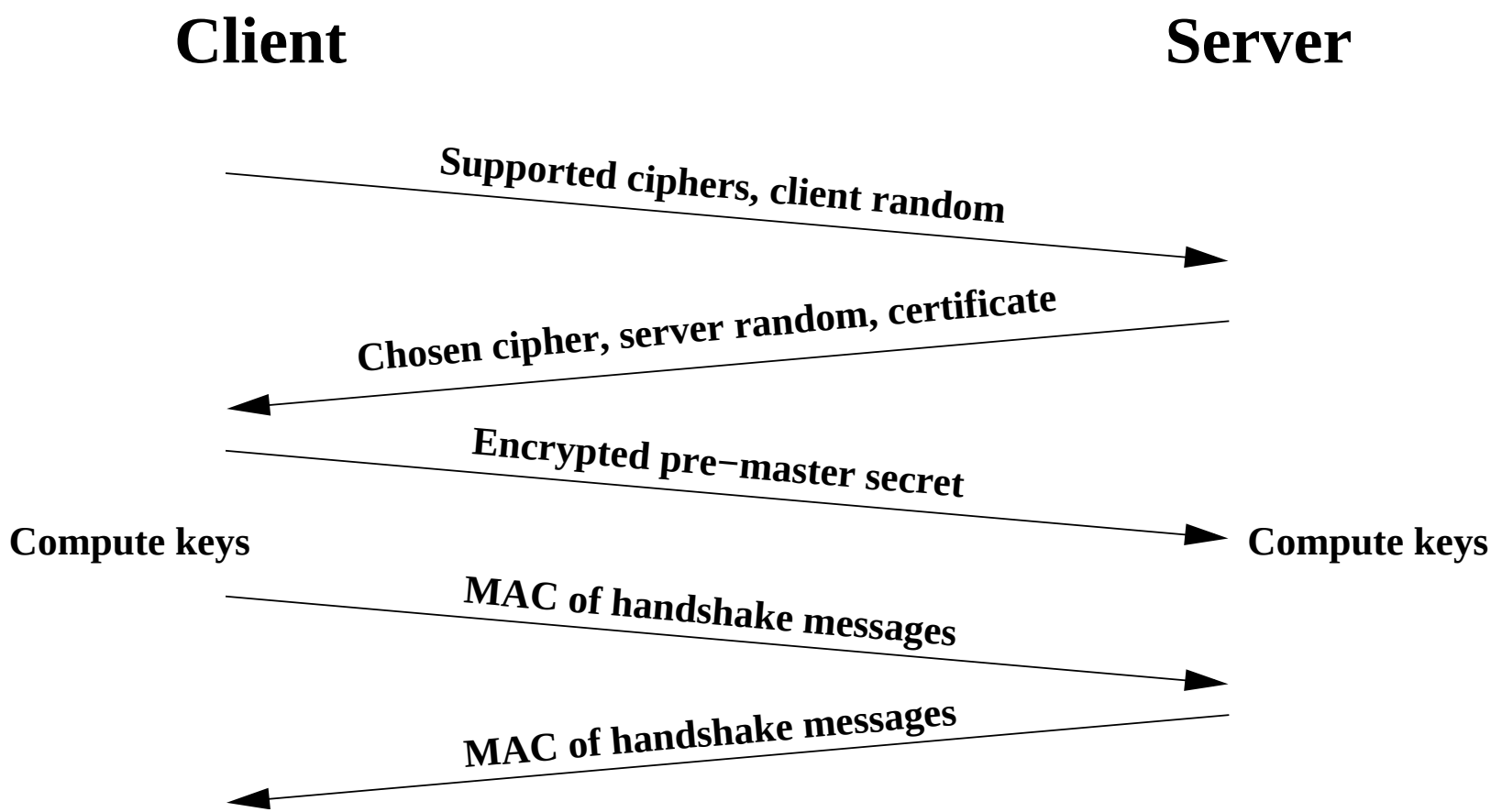
Purpose in more detail

- **Authentication based on certification authorities (CAs)**
  - Trusted third party with well-known public key
  - Certifies who belongs to a public key (domain name and real name of company)
  - Example: Verisign
- **What SSL Does Not Address**
  - Privacy
  - Traffic analysis
  - Trust management

Ciphersuites: Negotiating ciphers

- **Server authentication algorithm (RSA, DSS)**
- **Key exchange algorithm (RSA, DHE)**
- **Symmetric cipher for confidentiality (RC4, DES)**
- **MAC (HMAC-MD5, HMAC-SHA)**

Overview of SSL Handshake



From “SSL and TLS” by Eric Rescorla

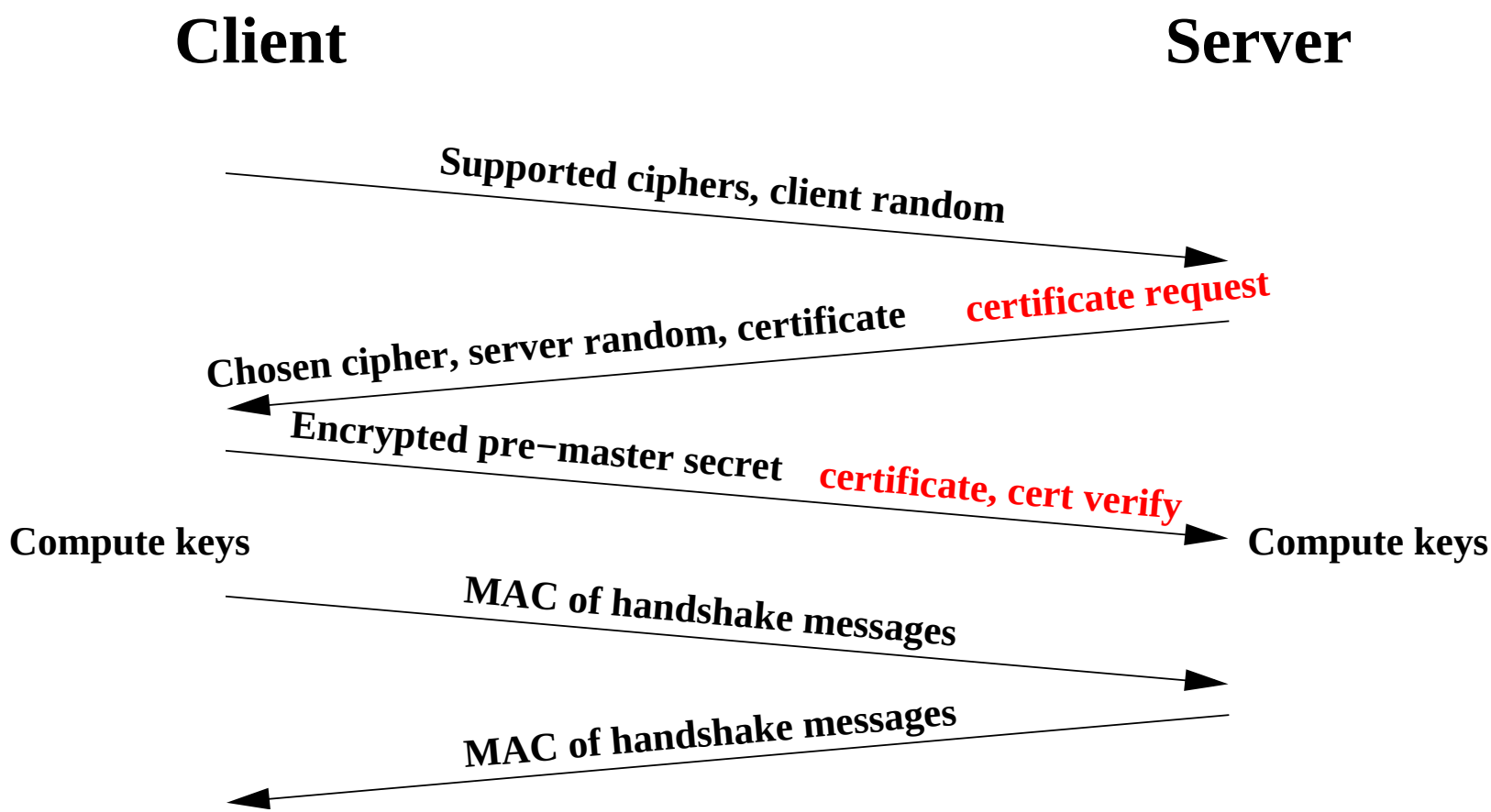
Simplified SSL Handshake

- Client and server negotiate on cipher selection.
- Cooperatively establish session keys.
- Use session keys for secure communication.

Client Authentication Handshake

- **Server requests that client send its certificate.**
- **Client signs a signed digest of the handshake messages.**

SSL Client Certificate

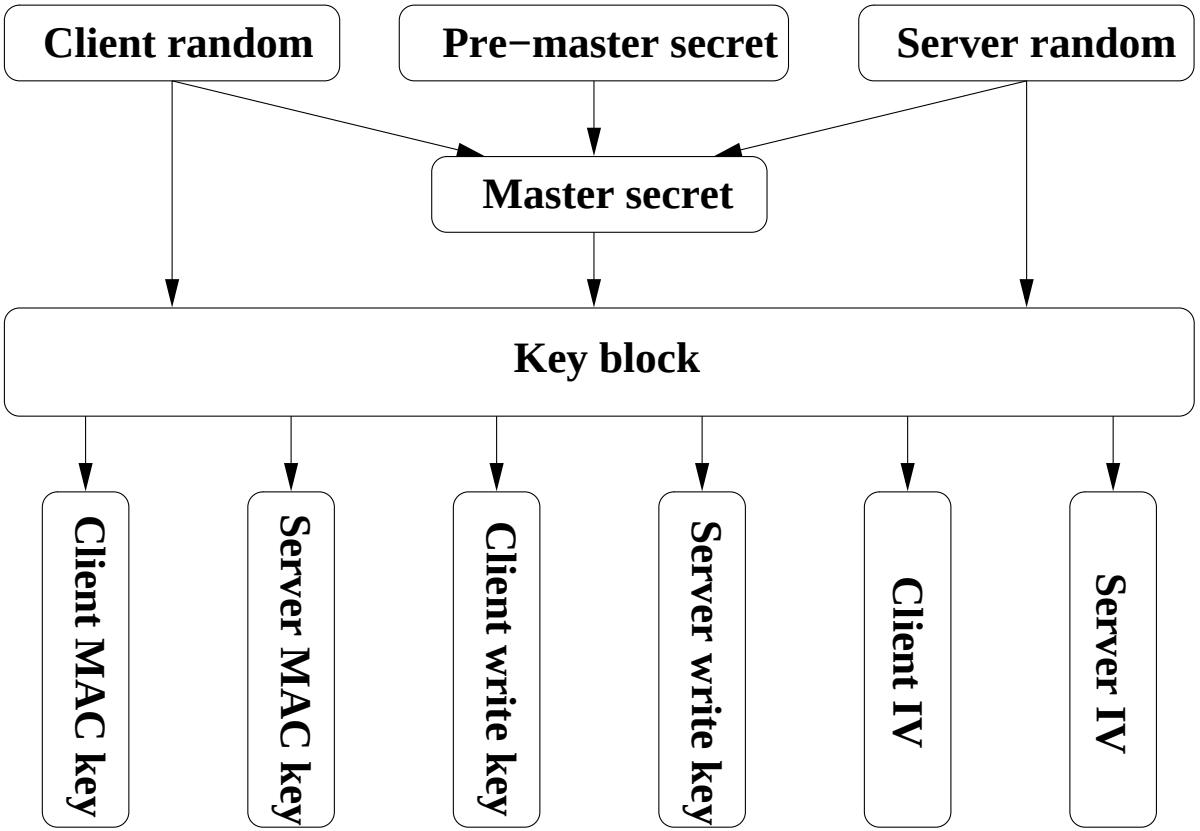


From “SSL and TLS” by Eric Rescorla

Establishing a Session Key

- **Server and client both contribute randomness.**
- **Client sends server a "pre-master secret" encrypted with server's public key.**
- **Use randomness and pre-master secret to create session keys:**
  - Client MAC
  - Server MAC
  - Client Write
  - Server Write
  - Client IV
  - Server IV

Establishing a Session Key



From “SSL and TLS” by Eric Rescorla

Session Resumption

- **Problem: Public key crypto expensive**
- **New TCP connection, reuse master secret.**
  - Avoids unnecessary public key cryptography.
- **Combines cached master secret with new randomness to generate new session keys.**
- **Works even when the client IP changes (servers cache on session ID, clients cache on server hostname).**

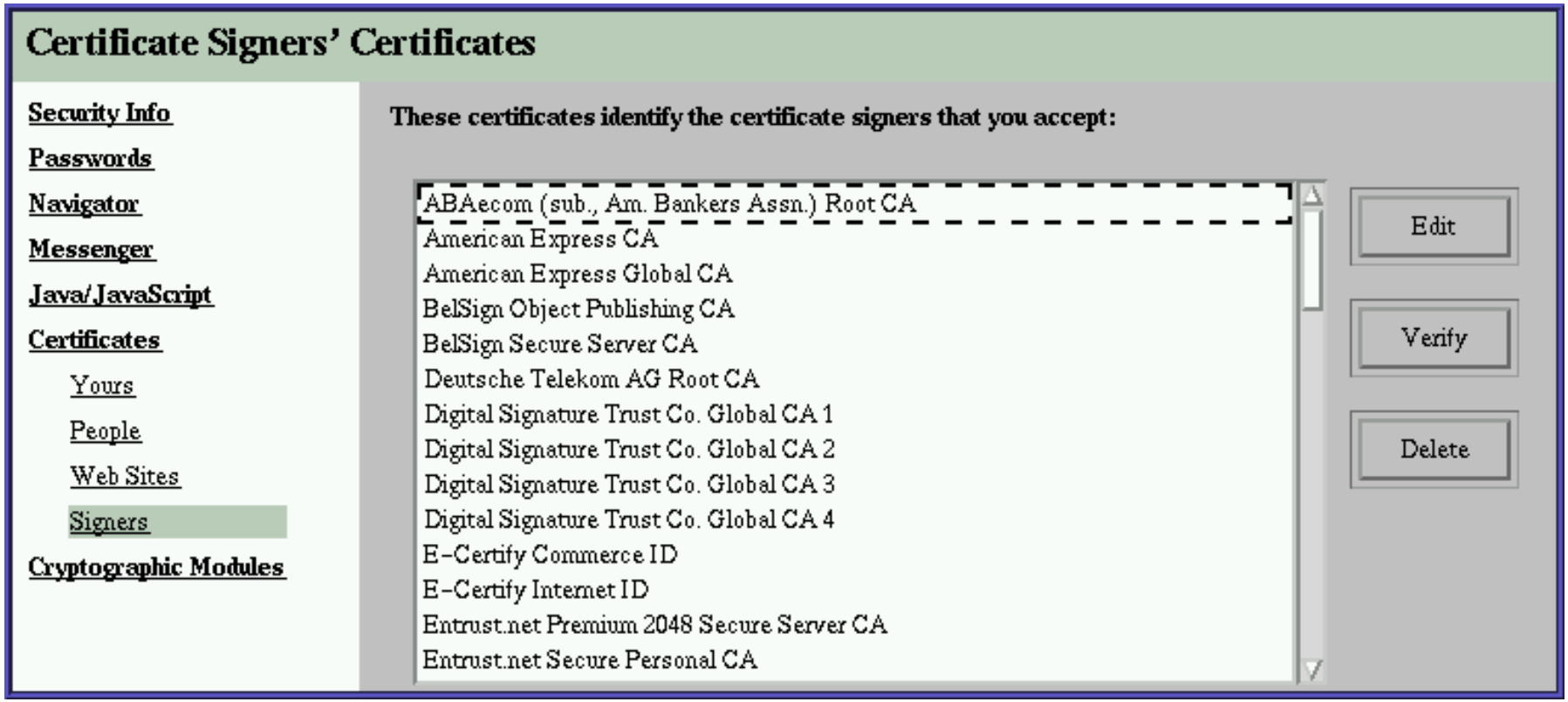
What does a CA-issued Certificate Mean?

- No one knows exactly.
- That a public key belongs to someone authorized to represent a hostname?
- That a public key belongs to someone who is associated in some way with a hostname?
- That a public key belongs to someone who has lots of paper trails associated to a company related to a hostname?
- That the CA has no liability?

How to get a Verisign certificate

- **Pay Verisign ($300)**
- **Get DBA license from city call ($20)**
  - No on-line check for name conflicts. . . can I do business as Microsoft?
- **Letterhead from company ($0)**
- **Notarized document (need driver's license) ($0)**
- **Conclusions:**
  - Easy to get a fraudulent certificate
  - Maybe not so easy to avoid prosecution afterwards
- **But that's only Verisign's policy**
  - Many CAs can issue certificates

So many CAs...


Certificate Signers' Certificates
Security Info
Passwords
Navigator
Messenger
Java/JavaScript
Certificates
Yours
People
Web Sites
Signers
Cryptographic Modules
These certificates identify the certificate signers that you accept:
ABAecom (sub., Am. Bankers Assn.) Root CA
American Express CA
American Express Global CA
BelSign Object Publishing CA
BelSign Secure Server CA
Deutsche Telekom AG Root CA
Digital Signature Trust Co. Global CA 1
Digital Signature Trust Co. Global CA 2
Digital Signature Trust Co. Global CA 3
Digital Signature Trust Co. Global CA 4
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100%

Interrogative adversaries

- **Adaptively query a Web server a reasonable number of times**
- **Treat server as an oracle for an adaptive chosen message attack**
- **Don't need any eavesdropping or other network tampering**
- **Anyone can do it, but surprisingly powerful attack**
  - C.f., adaptive chosen-ciphertext and chosen-message attacks—sounded improbable

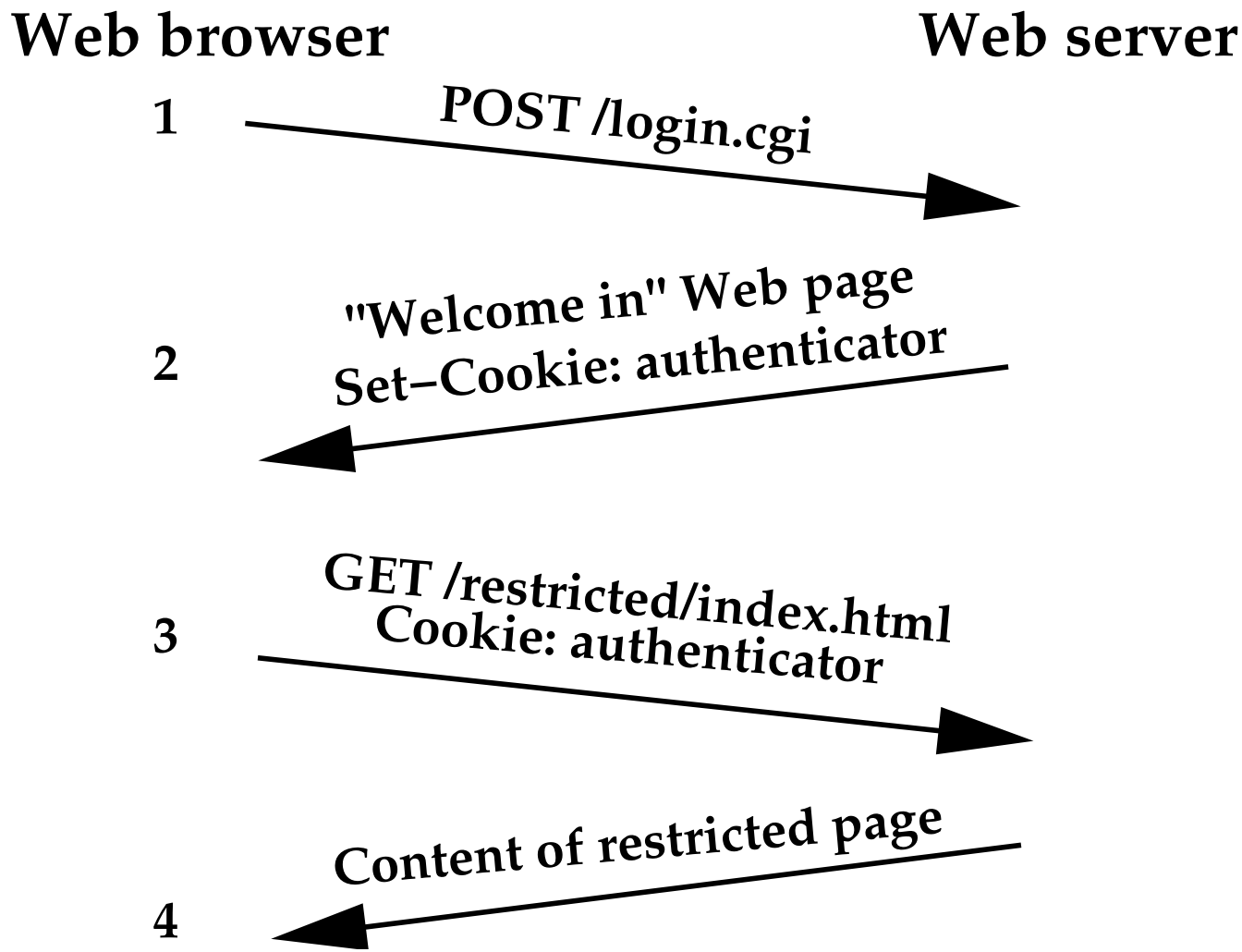
Cookies

- A Web server can store key/value pairs on a client
- The browser resends cookies in subsequent requests to the server
- Cookies can implement login sessions

Netscape cookie example

domain	.wsj.com
Path	/cgi
SSL?	FALSE
Expiration	941452067
Variable name	fastlogin
Value	bitdiddleMaRdw2J1h6Lfc

Cookies for login sessions



Why? Enter a password once per session

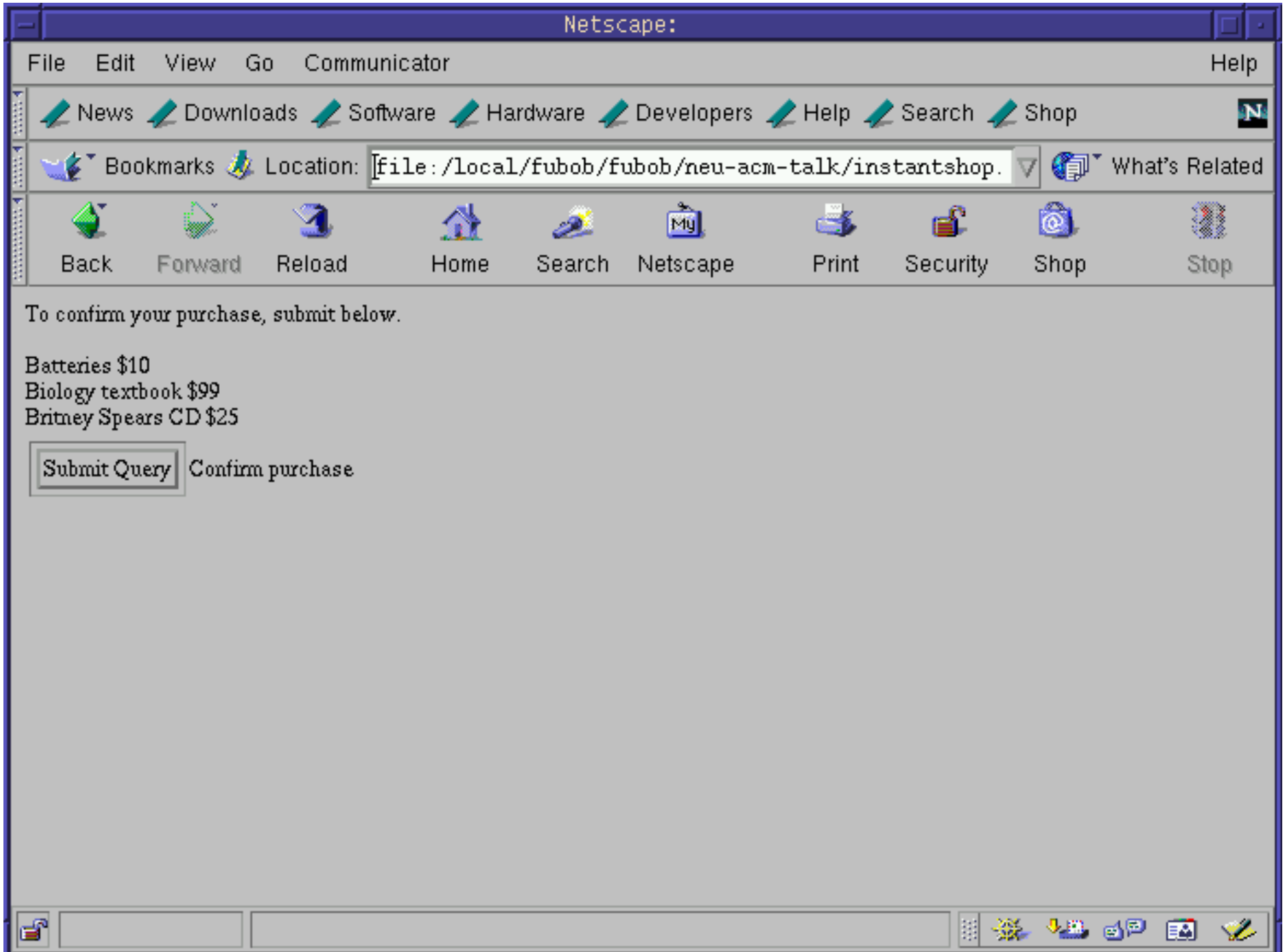
SSL can't protect data sent without SSL

- **Problem: Secure content can leak through plaintext channels**
- **Cookie file has flag to require SSL**
  - Not set by BankOnline.com
- **Trick user into visiting HTTP port**
  - Just need a link from an unrelated web page
  - Cookie automatically sent in the clear
  - Network eavesdropper can record it
  - Might as well not have used SSL

Letting clients name the price: Instant Shop

- **Problem: Servers trust clients not to modify HTML variables.**
- **Price determined by hidden variable in Web page.**
- **Make a personal copy of the web page. Modify it.**

Instant Shop example: What a browser displays



Instant Shop example: What's inside

```
<html><body>
 <form action=commit_sale.cgi>

<input type=hidden name=item1 value=10>Batteries $10<br>
<input type=hidden name=item2 value=99>Biology textbook $99<br>
<input type=hidden name=item3 value=25>Britney Spears CD $25<br>
<input type=submit>Confirm purchase
</form>
 </body></html>
```

Instant Shop example: Malicious client

```
<html><body>
 <form action=commit_sale.cgi>

<input type=hidden name=item1 value=0>Batteries $10<br>
<input type=hidden name=item2 value=0>Biology textbook $99<br>
<input type=hidden name=item3 value=0>Britney Spears CD $25<br>
<input type=submit>Confirm purchase
</form>
 </body></html>
```

Security through obscurity: NeBride.com

- **Problem: No cryptographic authentication at all**
- **Cookie (authenticator) is the username**
- **Create a cookie with someone's username**
  - Instant access to her name, address, phone number, e-mail address, wedding date and place, and password.

Predictable sequence numbers: fatbrain.com

- **Problem: Customer can determine the authenticator for any other user.**
- **Authenticators are sequence numbers in the URL.**

https://www.fatbrain.com/HelpAccount.asp?t=0&p1=fubob@mit.edu&p2=540555758
https://www.fatbrain.com/HelpAccount.asp?t=0&p1=nobob@mit.edu&p2=540555759

- **Guess a victim's sequence number by decrementing.**
- **Access to personal information**
- **Change address, receive password by email!**

Netscape: Fatbrain.com – Welcome to Your Account

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- Change Sign-in E-mail
- Change Password
- Edit Profiles
- Order Status
- Keep Me Posted
- Password Reminder

Welcome to Your Account.
Manage your account information, check on orders you have placed and more.

Use the menu bar on the left to:

- **Change Sign-in E-mail** -- change your sign-in e-mail. More ...
- **Change Password** -- change your signin password. More ...
- **Edit Profiles** -- edit your shipping, billing and payment information or create a new profile. More...
- **Order Status** -- view your order history or check the status of orders en route. More...
- **KeepMePosted** --view your email notifications. More...
- **Password Reminder** -- send yourself an email containing your password. More...

For detailed information on what you can do with Your Account, click the "More..." link next to your topic of interest or simply scroll down this page.

Thanks and we hope you enjoy the flexibility available with Your Account.

100%

wsj.com

- Authenticate subscribers with stateless servers
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The server interactive.wsj.com
wishes to set a cookie that will be sent
to any server in the domain .wsj.com
The name and value of the cookie are:
fastlogin=[redacted]

This cookie will persist until Sun Feb 25 07:26:53 2001

Do you wish to allow the cookie to be set?

OK Cancel

100% 100% of 7K (at 227 bytes/se

Background: The crypt() hash function

- **Hash function "salted" with 12 extra bits**
  - Prevent attacker from building dictionary of hashes of common passwords
  - Permute the hash function based on 12-bit seed
  - Prepend seed to hashed password for use in verification
- **Produces one-way function of password**
  - Only hashes first 8 characters
  - Encrypt 0s 25 times with password as key
- **Used by Unix login**
  - So put hashed password in world-readable `/etc/passwd`
  - To validate password, hash it and compare to stored hash

wsj.com analysis

- **Design: fastlogin = {user, $\mathtt{MAC}_{\mathtt{k}}$ (user)}**
- **Reality: fastlogin =**

  user + UNIX-crypt (user + server secret)
- **Easily produce fastlogin cookies**

username	crypt() Output	fastlogin cookie
bitdiddl	MaRdw2J1h6Lfc	bitdiddlMaRdw2J1h6Lfc
bitdiddle	MaRdw2J1h6Lfc	bitdiddleMaRdw2J1h6Lfc

- **Usernames matching first 8 characters have same authenticator**
- **No revocation or expiration.**
- **This is already bad, but it gets worse...**

Obtaining the server secret?

- **Adaptive chosen message attack**
- **Perl script queried WSJ with invalid cookies**
- **Runs in max 128×8 queries rather than intended 128^8 (1024 vs. 72057594037927936)**
- **1 sec/query yields 17 minutes vs. 10^9 years**
- **The key is "March20"**

How the attack works

Secret guess	username	crypt input	worked?
	bitdiddl	bitdiddl	Yes
A	bitdidd	bitdiddA	No
...	...	...	...
M	bitdidd	bitdiddM	Yes
MA	bitdid	bitdidMA	No
...	...	...	...
Ma	bitdid	bitdidMa	Yes
...	...	...	...
March20	b	bMarch20	Yes

Lack of cryptography: highschoolalumni.com

- **Problem: No cryptographic authentication at all**
- **Cookie authenticator is the public username and public user ID**

Netscape: HighSchoolAlumni.com-A Web Site for Alumni of US High Schools

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If you have forgotten your us

User name:

Password: ******

Login

The server www.highschoolalumni.com
wishes to set a cookie that will be sent
to any server in the domain .highschoolalumni.com
The name and value of the cookie are:
Beacon=hsareg.[illegible].hsa0.983078390.[illegible]

This cookie will persist until Tue Apr 27 06:07:05 2004

Do you wish to allow the cookie to be set?

OK Cancel

Connect: Host www

Leaking secrets: sprintpcs.com

- Problem: Secure content can leak through plaintext channels.
- Site didn't set SSL flag on cookies (like BankOnline.com)
- User logs in with HTTPS, then clicks back to main HTTP page.
- Vulnerable to passive eavesdropper.

Netscape: Sprint PCS – Your Account Manager

File Edit View Go Communicator Help

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Bookmarks Location: https://m27.sprintpcs.com/manage/general_manage_login.asp What's Related

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Sprint Sprint PCS®

Shop Manage

My Account | My Services | Customer Care | Tutorials | ? Help

Manage Your Sprint PCS Account Online

The server m27.sprintpcs.com
wishes to set a cookie that will be sent
to any server in the domain .sprintpcs.com
The name and value of the cookie are:
SPCS%5FRM=RM%5FON=Y&CN1=[illegible]&R115=[illegible]

This cookie will persist until Tue Mar 27 19:01:45 2001

Do you wish to allow the cookie to be set?

Cancel

Customer Sign In

Enter Your Sprint PCS Phone Number

617-[illegible]

Enter Your Account Password

****

Remember me

Sign In

Get my Password

Connect: Host m27.sprintpcs.com contacted. Waiting for reply...

Google

- **Google indexed many cookie files inadvertently places on the Web.**
- **Search for:**
  - `cookies.txt`
  - `avenuea.com FALSE FALSE` (cookie set by advertising co.)
  - `CERT7.DB` or `text:CERT7.DB` (in many cookies.txt files)

A simple scheme that works

$$\textbf{auth} = \texttt{expire} + \texttt{data} + \texttt{MAC}_k(\texttt{expire} + \texttt{data})$$

where $\texttt{MAC}$ **could be HMAC-SHA1,**

$\texttt{data}$ **could be a username or capability, and**

'+' denotes concatenation with a delimiter
Secure against interrogative adversary

But of course, MAC what you mean!

- **Sign *marshalled* data, not data with multiple interpretations**
- **badauth = MAC (key, username + expiration)**
  - (Alice, 21-Apr-2001) → MAC (key, Alice21-Apr-2001)
  - (Alice2, 1-Apr-2001) → MAC (key, Alice21-Apr-2001)
- **Same authenticator!**
- **Use unambiguous representation or delimiters**