Today in Cryptography (5830)

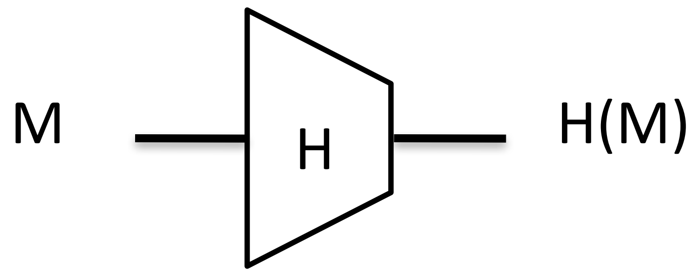
Password hashing
Password-based AE

Where we are at

- Authenticated encryption
  - Symmetric encryption providing confidentiality and integrity
- Hash functions
  - Collision resistance
  - Use as PRFs, MACs (HMAC)
- Today:
  - Password-based key derivation
  - Password-based AE

Cryptographic hash functions

A function H that maps arbitrary bit string to fixed length string of size n



SHA-256: n = 256 bits
SHA-512: n = 512 bits
SHA-3: n = 224, 256, 384, 512

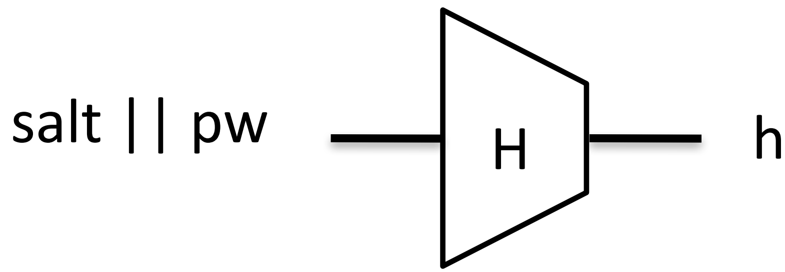
Many security goals asked of hash functions. Ideally, they behave as if they were a (public) random function.

Two specific security goals:

- Collision resistance
- Preimage resistance (one-wayness)

Password hashing

Password hashing. Choose random salt and store (salt,h) where:



The idea: Attacker, given (salt,h), should not be able to recover pw
A form of preimage resistance (one-wayness)

How to recover pw from (salt,h)?

For each guess pw':
    If H(salt||pw') = h then
        Ret pw'

Rainbow tables speed this up in practice by way of precomption. Large salts make rainbow tables impractical

Breaches are ubiquitous

⋮

32.6 million leaked (2012)
32.6 million recovered (plaintext!)

6.5 million leaked (2012)
5.85 million recovered in 2 weeks (SHA-1)

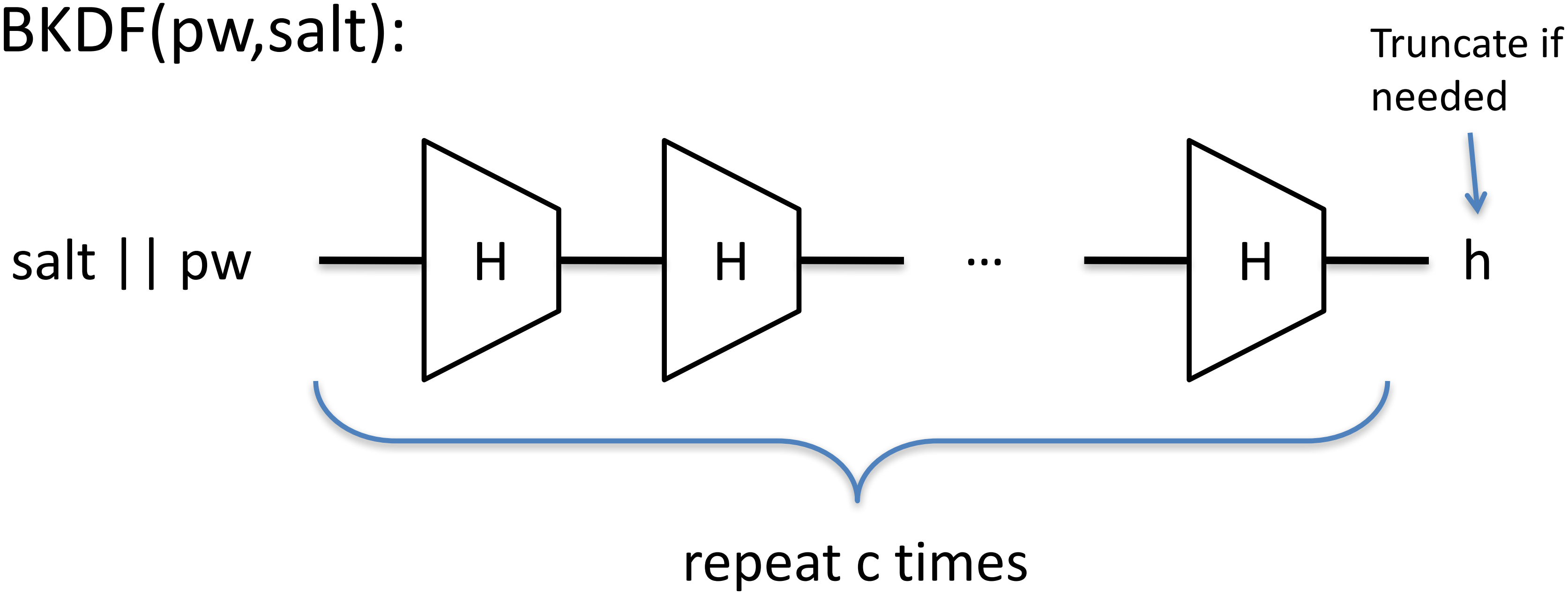
36 million accounts leaked (2013)
Encrypted, but with ECB mode

1 billion accounts (2013)
MD5 hashes

⋮

Password-based Key Deriviation (PBKDF)

PBKDF(pw,salt):



PKCS#5 standardizes PBKDF1 and PBKDF2, which are both hash-chain based. (PBKDF2 uses HMAC)

Slows down cracking attacks by a factor of c

AshleyMadison hack: 36 million user hashes

Salts + Passwords hashed using bcrypt with $c = 2^{12} = 4096$

4,007 cracked directly with trivial approach

CynoSure analysis: **11 million** hashes cracked

- >630,000 people used usernames as passwords
- MD5 hashes left lying around accidentally

http://cynosureprime.blogspot.com/2015/09/csp-our-take-on-cracked-am-passwords.html

```
ristenpart@Thomass-MacBook-Air:~/Dropbox/work/teaching/cs5830-spring2017/repo/slides$ openssl speed sha256
To get the most accurate results, try to run this
program when this computer is idle.
Doing sha256 for 3s on 16 size blocks: 4491209 sha256's in 2.98s
Doing sha256 for 3s on 64 size blocks: 2689214 sha256's in 2.98s
Doing sha256 for 3s on 256 size blocks: 1191470 sha256's in 2.99s
Doing sha256 for 3s on 1024 size blocks: 374944 sha256's in 2.98s
Doing sha256 for 3s on 8192 size blocks: 50404 sha256's in 2.99s
OpenSSL 0.9.8zg 14 July 2015
```

Say c = 4096. Generous back of envelope suggests that in 1 second, can test 367 passwords and so a naïve brute-force:

6 numerical digits	10^6 = 1,000,000	~ 2724 seconds
6 lower case alphanumeric digits	36^6 = 2,176,782,336	~ 68 days
8 alphanumeric + 10 special symbols	72^8 = 722,204,136,308,736	~ 22 million days

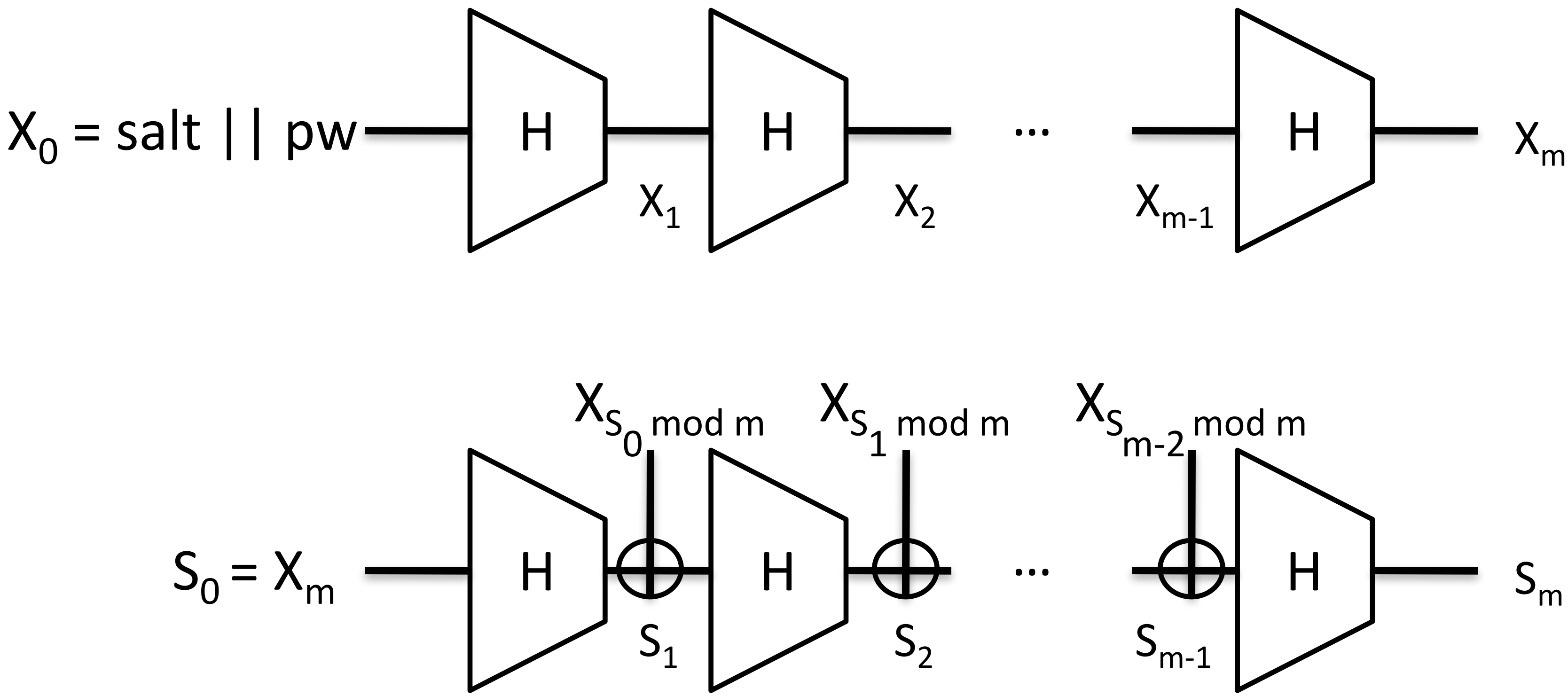
Special-purpose hashing chips (built for Bitcoin)

14,000,000,000,000 hashes / second

Can't be used easily for password cracking, but concern about ASICs (application-specific integrated circuits) remains

Scrypt and memory-hard hashing

- Increase time & memory needed to compute hash.
  - This makes ASIC implementations harder
- Scrypt



Facebook password onion

```
$cur  = ‘password’
$cur  = md5($cur)
$salt = randbytes(20)
$cur  = hmac_sha1($cur, $salt)
$cur  = remote_hmac_sha256($cur, $secret)
$cur  = scrypt($cur, $salt)
$cur  = hmac_sha256($cur, $salt)
```

Evolution of their password hashing over time

Limitations:

- Can’t rotate secret
- Can’t do cryptographic erasure for compromise clean-up

Pythia: better approach allowing secret key rotations

http://pages.cs.wisc.edu/~ace/pythia.html

Simple typo-tolerant password checking

tom, Password1

tom	G_K(password1)
alice	G_K(123456)
bob	G_K(p@ssword!)

Easily-corrected typos admit simple correctors:

$f_{caps}(x)$ = x with case of all letters flipped

$f_{1st\text{-}case}(x)$ = x with first letter case flipped, if it is letter

…

Define set C of corrector functions. Let h = G_K(password1)

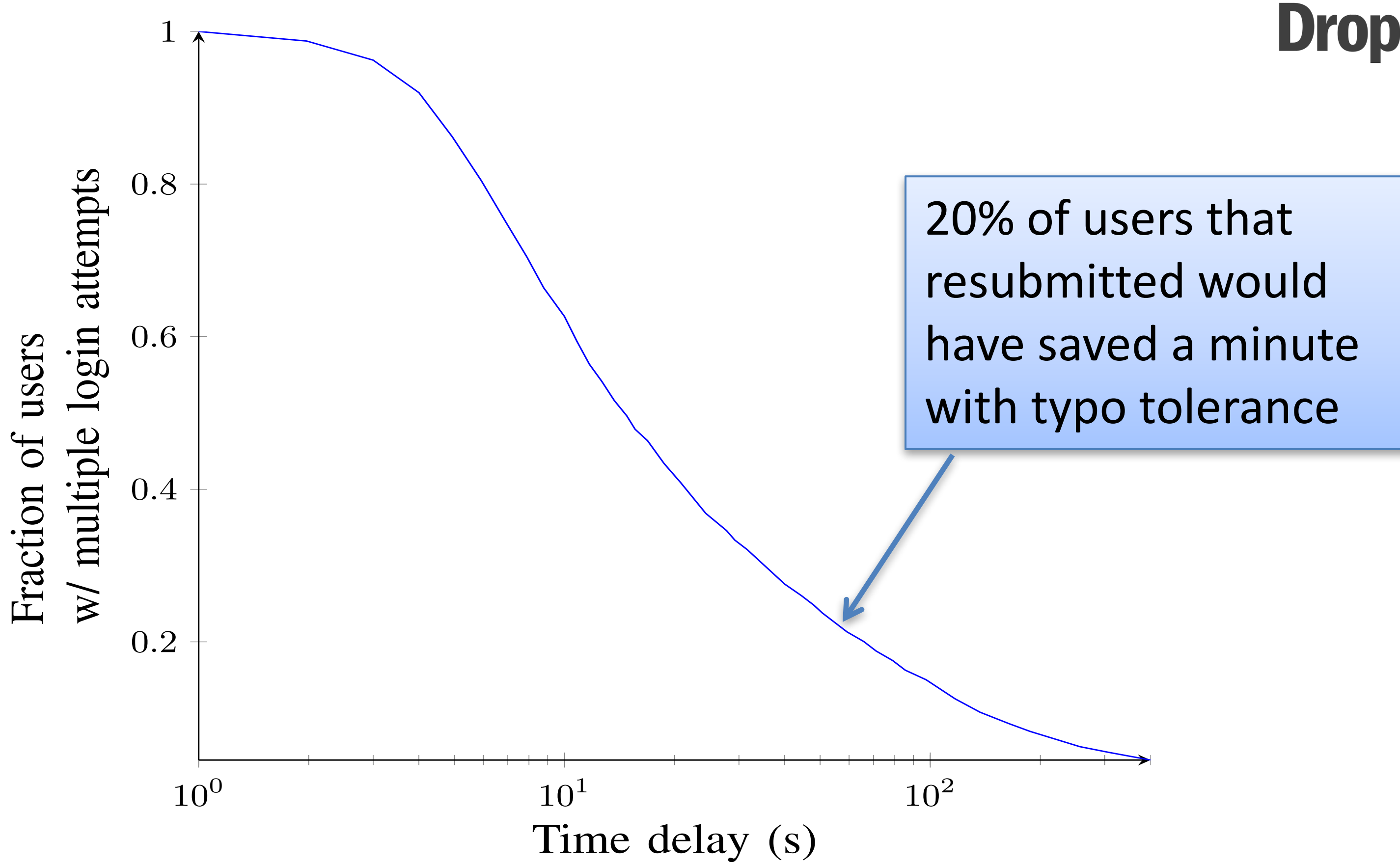
Relaxed checker:

```
If G_K(Password1) = h then Return 1
For each f in C:
    If G_K( f(Password1) ) = h then Return 1
Return 0
```

G_K is a password hashing scheme, possibly using secret K

Dropbox experiments

Utility of caps lock, first letter capitalization, removing last character



Typo tolerance would add several person-months of login time

3% of ***users*** couldn't log in during 24 hour period, but could have with one of Top 3 correctors

Empirical security analyses

Use password leaks as empirical password distributions

Typo-tolerant checker estimates distribution using RockYou

Simulate attacker following greedy strategy for typo-tolerant checker
Assume attacker knows challenge distribution exactly

q = 100

Challenge Distribution	Correctors	Exact success	Greedy strategy
phpbb	C_{top2}	5.50%	5.50%
phpbb	C_{top3}	5.50%	5.51%
Myspace	C_{top2}	2.86%	2.89%
Myspace	C_{top3}	2.86%	3.18%

Attackers that estimate challenge distribution incorrectly:

Often perform worse when trying to take advantage of tolerance
(See paper for details)

We are running new study now

- Personalized typo-tolerant system
  - Learns your specific typos over time
- We have prototype implementation for Mac, Linux

https://www.cs.cornell.edu/~rahul/projects/adaptive_typo.html

- Be great if you can participate!

Another application of PBKDFs: PW-based encryption

<u>PWEnc(pw,M):</u>
salt <-$ $\{0,1\}^{256}$
K <- PBKDF(pw,salt)
C <- Enc(K,M)
Return (salt,C)

<u>PWDec(pw,salt||C):</u>
K <- PBKDF(pw,salt)
M <- Dec(K,C)
Return M

Enc is a *one-time-secure* AE scheme:

CTR-then-HMAC, constant IV for CTR

CBC-then-HMAC, constant IV for CBC mode

What's wrong with this?

```
import base64
from cryptography.fernet import Fernet
from cryptography.hazmat.primitives import hashes
from cryptography.hazmat.backends import default_backend

def get_key(password):

    digest = hashes.Hash(hashes.SHA256(), backend=default_backend())
    digest.update(password)
    return base64.urlsafe_b64encode(digest.finalize())

def encrypt(password, token):
    f = Fernet(get_key(key))
    return f.encrypt(bytes(token))

def decrypt(password, token):
    f = Fernet(get_key(password))
    return f.decrypt(bytes(token))
```

http://incolumitas.com/2014/10/19/using-the-python-cryptography-module-with-custom-passwords/

Crypto library API challenges

- Tension between *opinionated API, security and application needs*
  - Opinionated:
    Low-flexibility for caller (e.g., Fernet)
  - Un-opinionated:
    High-flexibility for caller (e.g., Hazmat, OpenSSL)
- Opinionated best for security, but only if it handles application needs
  - Developers will work around your API, most likely insecurely!

Cryptography.io feature request

- https://github.com/pyca/cryptography/issues/1333
- Need a recipe for password-based Fernet
- The game plan:
  - Paul G., myself will come up with draft spec
    - Scrypt / PBKDF + Fernet-AE
    - How to choose salt? How to serialize?
    - How to allow setting parameters (e.g., iteration count)?
  - Get feedback from Paul Kehrer, you all
  - Homework 4: individual implementations
    - Make sure they inter-operate
  - Extra credit: group project to refine spec, code

Summary

- Password hashing
  - Make hashing resource-intensive (time and/or memory)
  - Slows down brute-force cracking attacks
- Password-based authentication
  - Password onions
  - Typo-tolerance
- Password-based encryption