Engineering Robust Server Software

Security

Significant portions based on slides from
Micah Sherr @ Georgetown

Security

- First major topic: **security**
  - What do we mean by security?

Security

- First major topic: **security**
  - What do we mean by security?

The CIA Triad

- **Confidentiality**: things are kept secret
- **Integrity**: things cannot be tampered with
- **Availability**: things are useable (for users who are supposed to be able to)

- A key topic that helps all of the above:
  - **Authentication**: things can figure out that you are who you claim to be

Confidentiality: Example 1

Alice

Leftover Food in HH 218

Eve

Bob

Confidentiality: Example 1

f(Leftover Food in HH 218)
= Al481manj417a@#1naL

f^{-1}(Al481manj417a@#1naL)
=Leftover Food in HH 218

Alice

Al481manj417a@#1naL

Bob

Eve

??

Confidentiality: Example 2

```
[eve@linux] $ cat ~alice/secret.txt
ls: /home/alice/secret.txt : Permission denied
[eve@linux] $
```

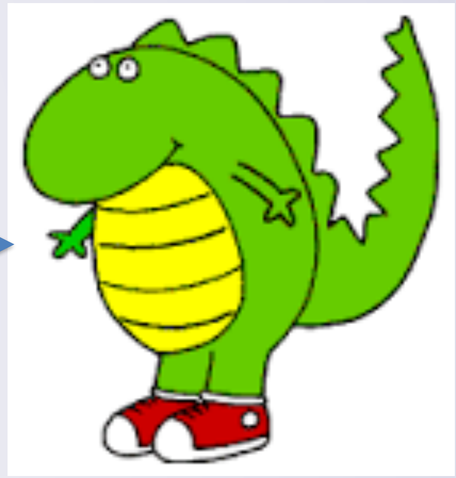
Integrity: Example 1

Alice

Please send $1000
to account 123456
Thanks, Alice

Eve

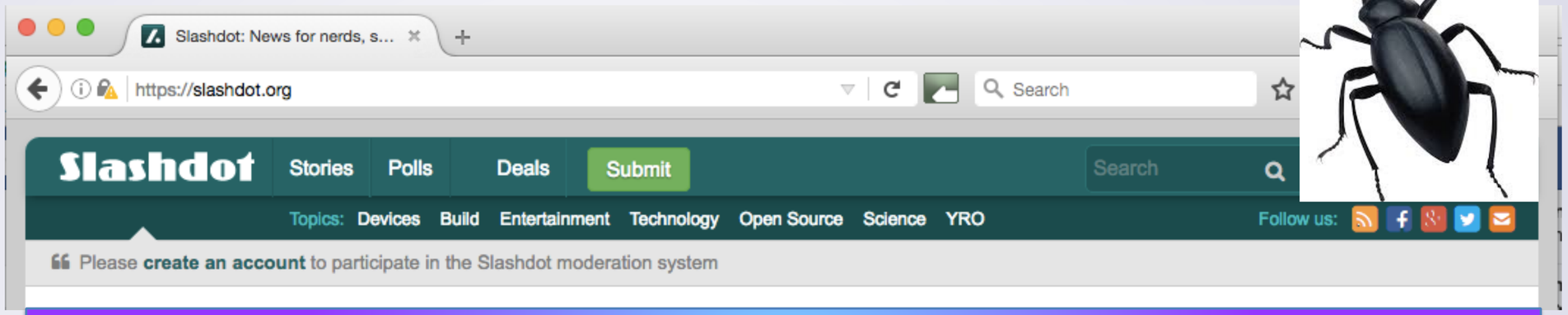
Please send $1000
to account 467129
Thanks, Alice



Bob

Integrity: Example 2

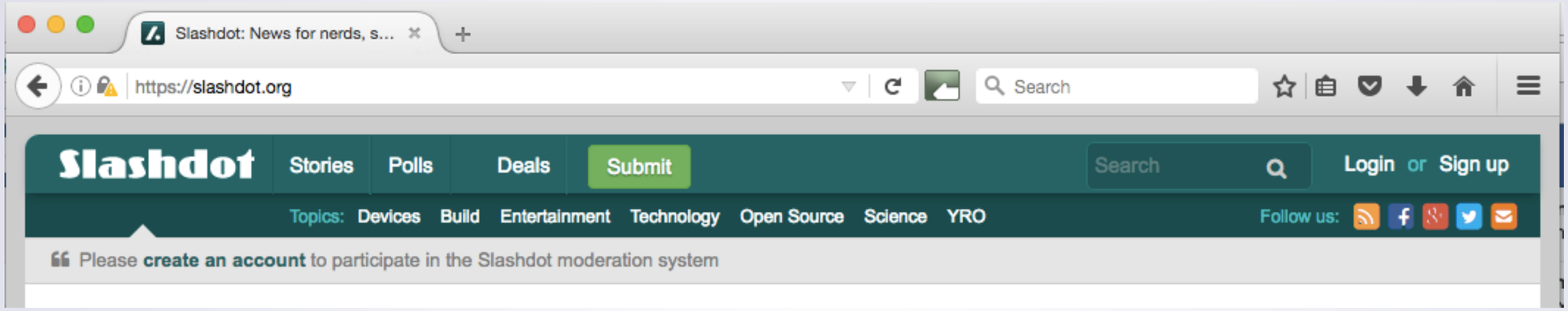
Alice



Eve's awesome software services! 20% off. This week only!

Eve

Security Difficulty: Hard To Detect Compromises



Alice

Is my browser hacked??

Confidentiality + Integrity

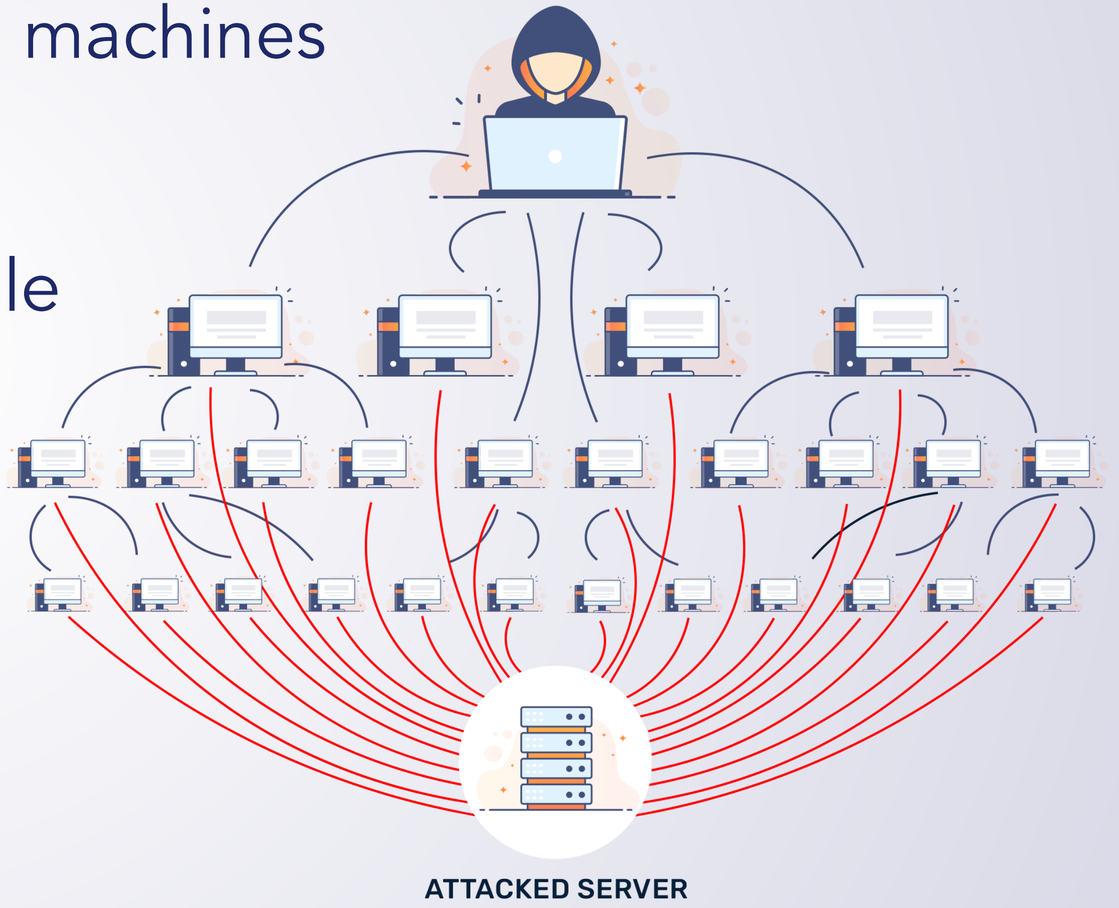
Physical attacks:
- Hardware support for defense: e.g, SGX

Availability: Example 1

- Distributed Denial of Service (DDoS)
- Attacker gets a bunch of compromised machines
- Tells all of them to visit victim site
- Victim has more traffic than it can handle
- Legitimate users can’t access the site

  – too slow/crashed

A distributed denial of service (DDoS) attack



Availability: Example 2

- Attacker finds flaw in your website – now they can run any database commands they want (SQL injection attack)
- One cheap and destructive thing they can do:
  DROP DATABASE site_database;

- Site loses all database data (unless it was backed up – covered later)

Authentication

Hi I'm Alice

Please buy 1000 shares of foobar corp with the money in my account

Wait… Are you really Alice?
…Prove it!

Authentication

- Kinds of authentication:
  - Something you know (e.g., password)
  - Something you have (e.g., your phone)
  - Something you are (biometrics)
- Multi-factor:
  - When you use two or more of the above categories

Authentication

- Two common and relevant modes of authentication for servers:

- **Password (still most common, sadly)**
  - How good are your passwords?
- Cryptographic keys
  - ssh keys

Speaking of Authentication…

Alice

username: alice
password: m$1iKa^PQ1t#aRn7

- What would happen if Alice sent her password cleartext?

Speaking of Authentication...

Alice

username: alice
password: m$1iKa^PQ1t#aRn7

Eve

Now I know Alice's password!

Speaking of Authentication…

Alice

(encrypted username/password)

- Ok, so Alice encrypts username/password…

Speaking of Authentication…

Alice

(encrypted username/password)

Username	Password
alice	m$1iKa^PQ1t#aRn7
bob	lWi8@P(~qtY3oR
eve	,$ql)Pq>4iQldV7

- VERY BAD: DO NOT DO
  - Server stores password in plaintext

Duke UNIVERSITY

Speaking of Authentication…

Alice

(encrypted username/password)

Username	Password
alice	m$1iKa^PQ1t#aRn7
bob	lWi8@P(~qtY3oR
eve	,$ql)Pq>4iQldV7

Sweet! Now I have everyone's password… Maybe they use them on other sites too!….

- VERY BAD: DO NOT DO
  - Server stores password in plai

Speaking of Authentication…

Alice

(encrypted username/password)

Username	PasswdHash
alice	A1C399F501AB5432
bob	F09485ACB154A
eve	154FABC9F523C

- Better, but still wrong
  - Server stores hashes: computes hash(password) + compares to table

Speaking of Authentication…

Alice

(encrypted username/password)

Username	PasswdHash
alice	A1C399F501AB5432
bob	F09485ACB154A
eve	154FABC9F523C

Now I have hashes… What can I do with them?

- Better, but still wrong
  - Server stores hashes: computes hash(password) + compares to table

Eve: Breaks Hashes (All at Once)

```
Len = 1
while (1) {
 for each string s of length Len{
    int h = hash(s)
    users = mapOfStolenData.lookup(h);
    if (users is not empty) {
        print users + "password =" + s
    }
 }
 Len ++;
}
```

Difficulty to Crack?

- Generally 95 possible characters
- Number of possible strings for a given length:

Length	Num Strings (95^L)	Time if 500K hash/sec
4	81 M	2 minutes
6	735 B	17 days
8	6E+15	400 years
10	6E+19	3M years

Is 8 characters safe?

Eve: Breaks Hashes (All at Once)

```
Len = 1
while (1) {
 for each string s of length Len{
    int h = hash(s)
    users = mapOfStolenData.lookup(h);
    if (users is not empty) {
        print users + "password =" + s
    }
 }
 Len ++;
}
```

Eve can speed up her attack by exploiting the fact that..

…this code is embarrassingly parallel

Difficulty to Crack?

- Generally 95 possible characters
- Number of possible strings for a given length:

Length	Num Strings (95^L)	Time if 500K hash/sec	Time if 1.5T hash/sec
4	81 M	2 minutes	< 1 sec
6	735 B	17 days	< 1 sec
8	6E+15	400 years	~1 hour
10	6E+19	3M years	~1 year

I just bought 100 GPUs..

Password Cracking

- That analysis is for
  - Every possible password (every combination)
  - Gets ALL stolen hashes at once
    - 10,000 users
    - 1 hour: every password of length 8 (thousands of passwords)
- Can probably speed up by using common passwords
  - password
  - 1234
  - …

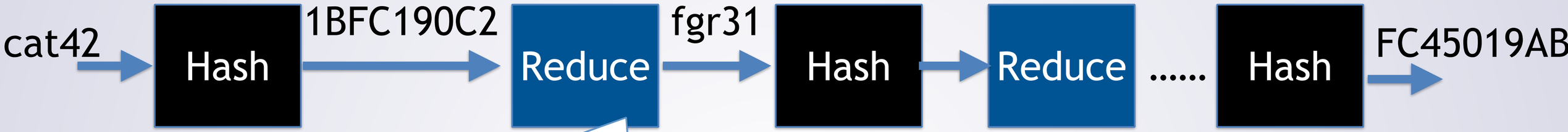
Pre-Computation

I'm going to try to hack your server soon. But once you discover it, you might warn your users, and they might change their passwords… How can I prepare?

Password Cracking (cont'd)

- Can also trade **time** for **space**
  - Execution time/memory (or disk) requirement tradeoff
- Option 1 build map hash -> password (e.g., before stealing hashes)
  - 95^6 * 16 bytes/entry ~= 10 TB [HDD: costs about $300—$400]
  - 95^8 * 16 bytes/entry ~= 96,540 TB [seems expensive]
- Option in the middle?
  - Pre-compute some things
  - Make attack faster
  - Do not require so much storage?

Rainbow Tables

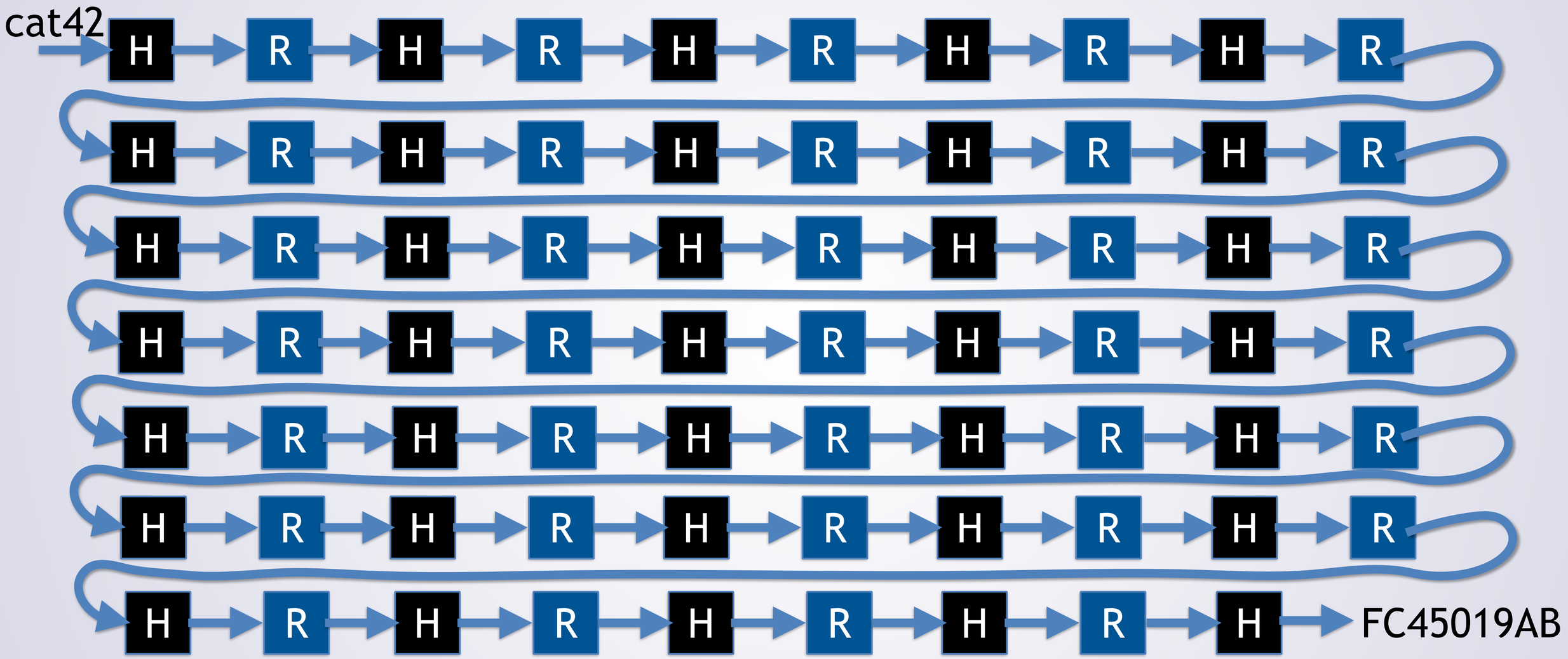


The **reduce**: Convert a hash to a possible password.

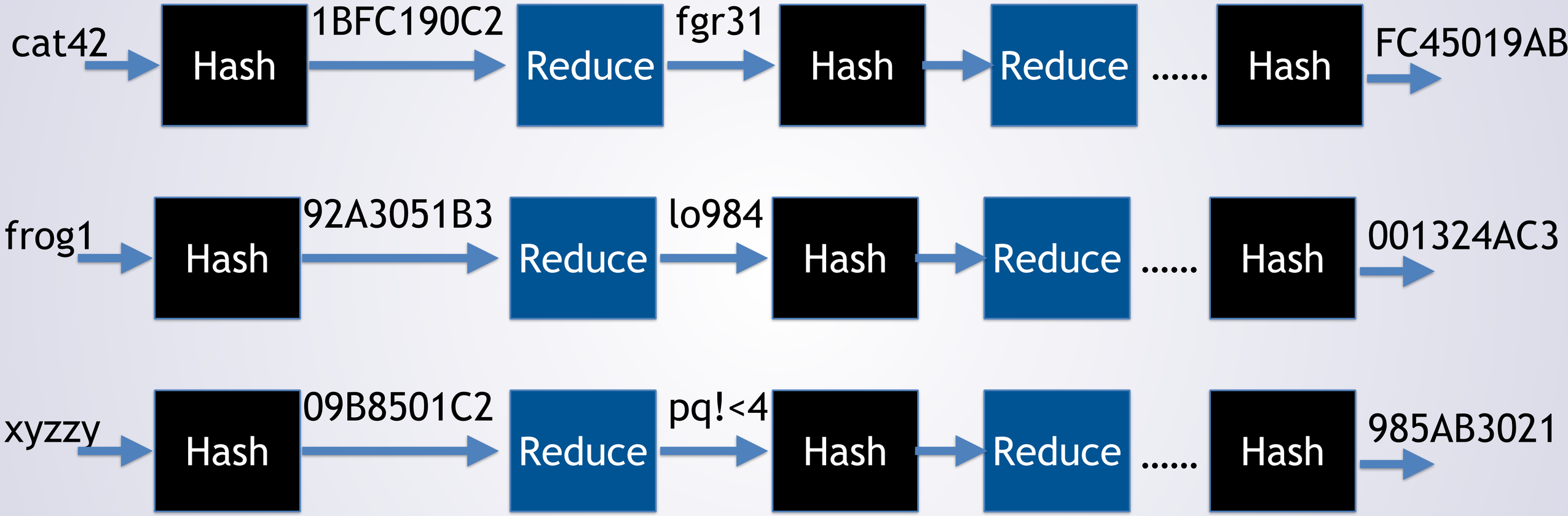
Note: no chance that the password hashes to the given value! This isn't a "reverse the hash" function, since that's our overall goal!

Just an arbitrary mapping so that the set of all strings in all the chains (the first one plus all the reduces, for all the chains) represent most/all of the password space.

Rainbow Tables



Rainbow Tables



Rainbow Tables

cat42

FC45019AB

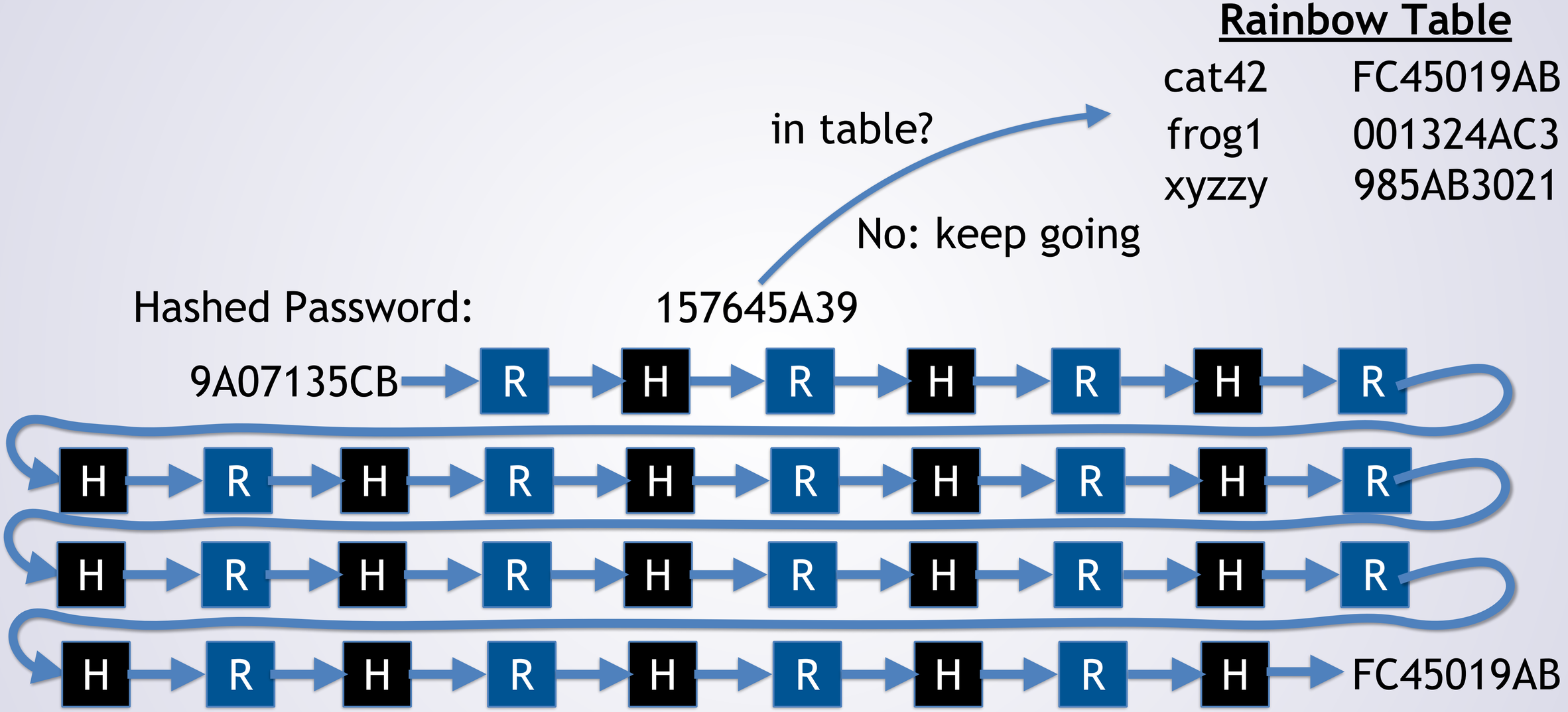
frog1

001324AC3

xyzzy

985AB3021

Rainbow Tables

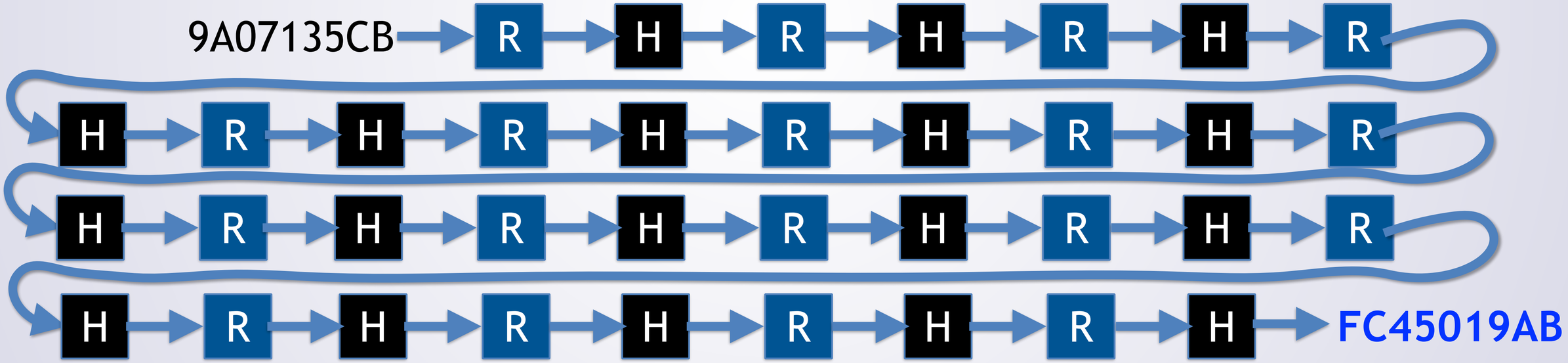


Rainbow Tables

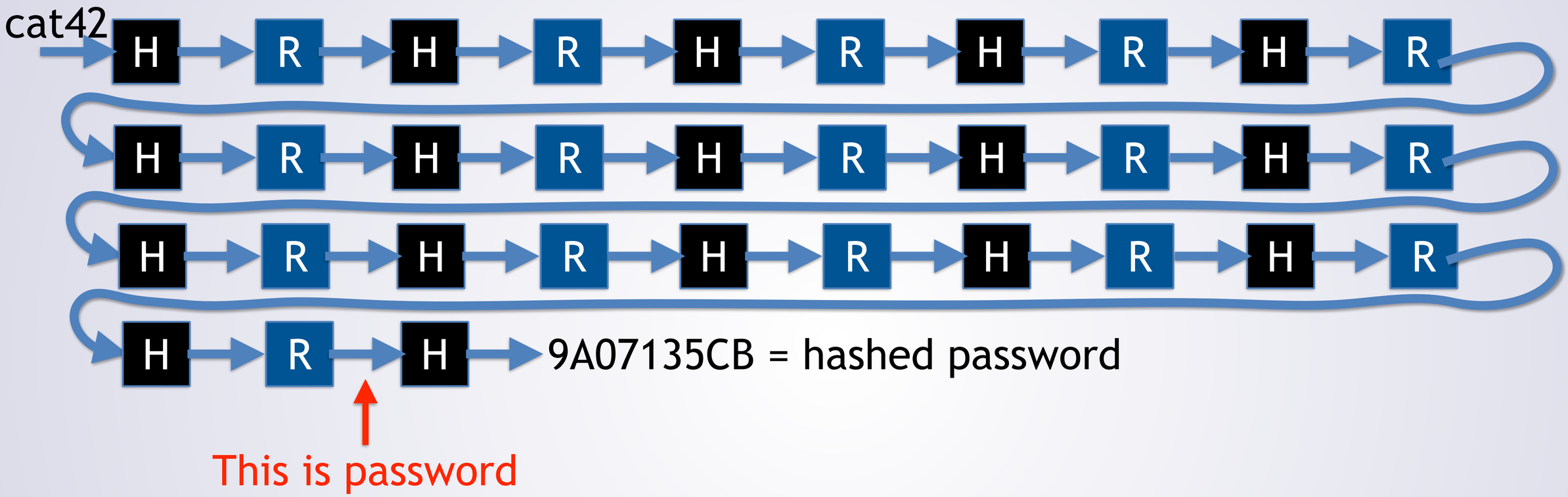
Rainbow Table

cat42	FC45019AB
frog1	001324AC3
xyzzy	985AB3021

Hashed Password:



Rainbow Tables



Rainbow Tables

- If we have C chains of length L, and the password is in one of our chains, then a rainbow table lets us break the password in
  - **A**: O(lg (C) * L^2) time
  - **B**: O(C^2 * lg(L)) time
  - **C**: O(L) time
  - **D**: O(C*L) time 

Space vs Time

- Full map
  - 95^6 * 16 bytes/entry ~= 10 TB [HDD: costs about $500]
  - 95^8 * 16 bytes/entry ~= 96,540 TB [seems expensive]
- Rainbow table (w/ **1B hashes/chain**):
  - 95^6 * 16 bytes/entry ~= 10 KB [fits in L1 cache]
  - 95^8 * 16 bytes/entry ~= 96MB [fits in RAM]
  - 95^10 * 16 bytes/entry ~= 830 GB [cheap hard disk]

Important Lesson: HASHING IS NOT ENOUGH

Speaking of Authentication…

Alice

(encrypted username/password)

Username	PasswdHash	Salt
alice	A1C399F501AB5432	1A45FB9C072BC90A
bob	F09485ACB154A	9841ABCD416790
eve	154FABC9F523C0	FAB981230CDBEA

- **Correct (assuming we get everything else right)**
  - Server stores hashes + **salt**: computes hash(password, **salt**)

Speaking of Authentication...

Username	PasswdHash	Salt
alice	A1C399F501AB5432	1A45FB9C072BC9
bob	F09485ACB154A	9841ABCD416790
eve	154FABC9F523C0	FAB981230CDBEA

To crack Alice's password: try various combinations of strings (s) hash (s, 0x1A45FB9C072BC9)

To crack Bob's password: try various combinations of strings (s) hash (s, 0x9841ABCD416790)

What Does Salt Get Us?

- Pre-computation is ineffective
  - Build a map for each possible salt?
    - 64 bit salt-> will take forever + be huge
  - Rainbow tables?
    - Still need rainbow table for each salt
    - Expensive to build/store
- Crack each user's password **separately**
  - **Rather than in parallel**
  - Slowdown factor of number of users

What Does Salt Get Us?

Now this analysis is for **ONE** user's password (not all at once)
Multiply by number of user's to do them all…

Length	Num Strings (95^L)	Time if 500K hash/sec	Time if 1.5T hash/sec
4	81 M	2 minutes	< 1 sec
6	735 B	17 days	<1 sec
8	6E+15	400 years	~1 hour
10	6E+19	3M years	~ 1 year

Speaking of Authentication…

- **Correct (assuming we get everything else right)**
  - Server stores hashes + **salt**: computes hash(password, **salt**)

Speaking of Authentication…

- What else do we need to get right?
  - Sufficiently long (>=64 bits), **random** salt
  - Secure hash: **SHA-2 or SHA-3**
    - NOT **MD5, SHA-0, or SHA-1**
  - Use **key stretching** algorithm
    - E.g., PBKDF2 (also popular: bcrypt)

Key Stretching

- Do we want hashing algorithm to be **slow** or **fast**?
  - **A**: slow
  - **B**: fast

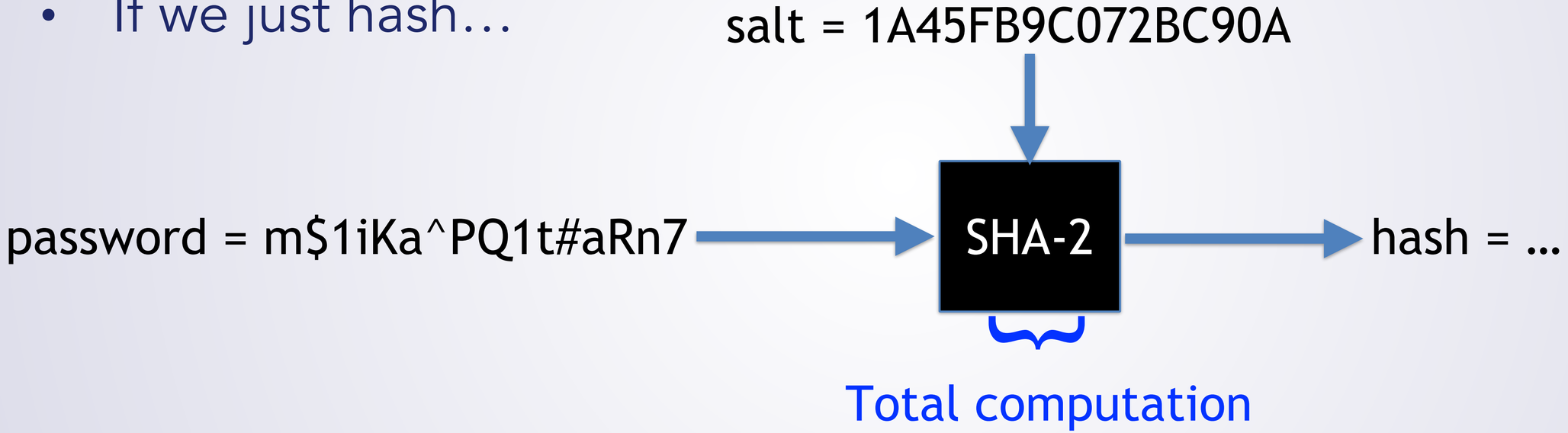
Key Stretching

- Do we want hashing algorithm to be **slow** or **fast**?

Length	Num Strings (95^L)	Time if 500K hash/sec	Time if 1.5T hash/sec
4	81 M	2 minutes	< 1 sec
6	735 B	17 days	< 1 sec
8	6E+15	400 years	~1 hour
10	6E+19	3M years	~ 1 year
		Slow :)	Fast :(

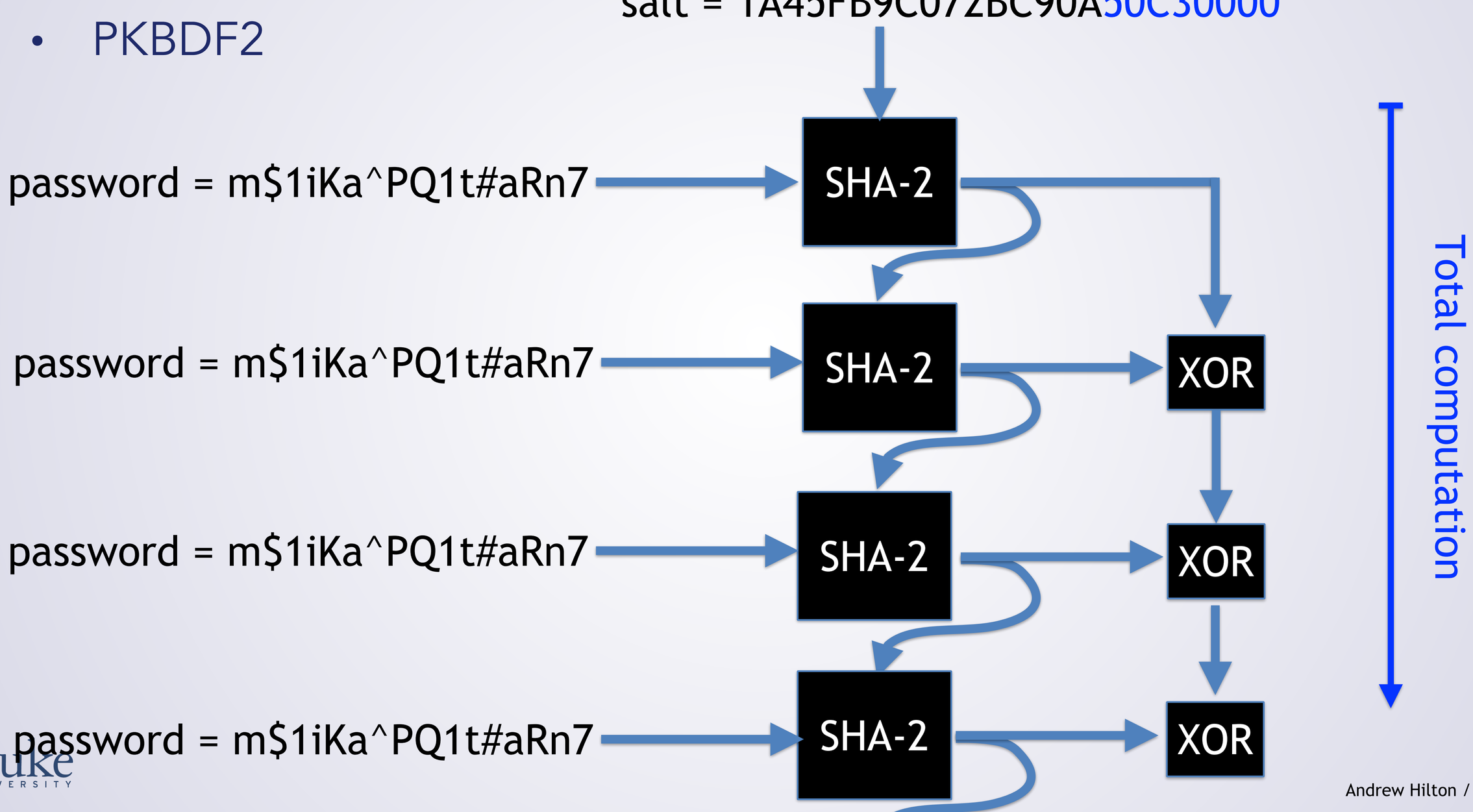
Key Stretching

- Do we want hashing algorithm to be **slow** or **fast**?
  - Want attackers to have to spend more work to break hashes
- If we just hash…



Key Stretching

- PKBDF2



Speaking of Authentication…

- What else do we need to get right?
  - Sufficiently long (>=64 bits), **random** salt
  - Secure hash: **SHA-2 or SHA-3**
    - NOT **MD5, SHA-0, or SHA-1**
  - Use **key stretching** algorithm
    - E.g., PBKDF2 (also popular: bcrypt)
  - Do NOT screw up and weaken things:
    - https://arstechnica.com/security/2015/09/once-seen-as-bulletproof-11-million-ashley-madison-passwords-already-cracked/
  - Do NOT try to invent things yourself!

Duke UNIVERSITY

Use Libraries That Do It Right

- Hashing in C/C++?
  - Use libssl
- Hashing in python?
  - Use hashlib: `hashlib.pbkdf2_hmac('sha512', pwd, salt, itrs)`
- Authentication in Django?
  - https://docs.djangoproject.com/en/2.0/topics/auth/passwords/

Wrap Up

- Intro to security:
  - Confidentiality
  - Integrity
  - Authentication
    - Much discuss of password safety
  - Availability
- Next time:
  - Cryptography