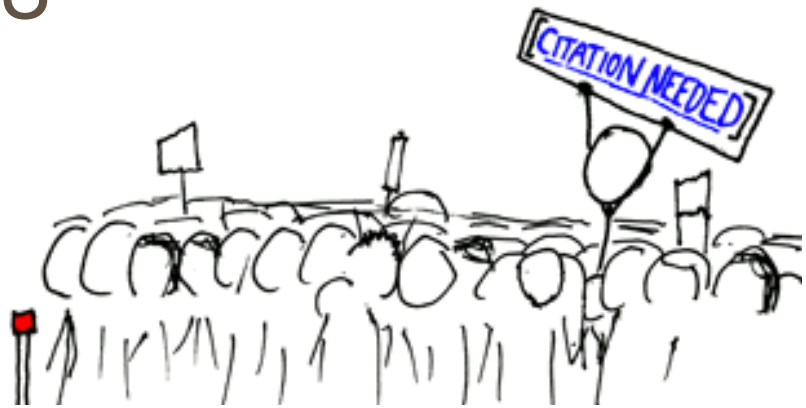
Security
[help from XKCD, Christo Wilson]

Lecture 13

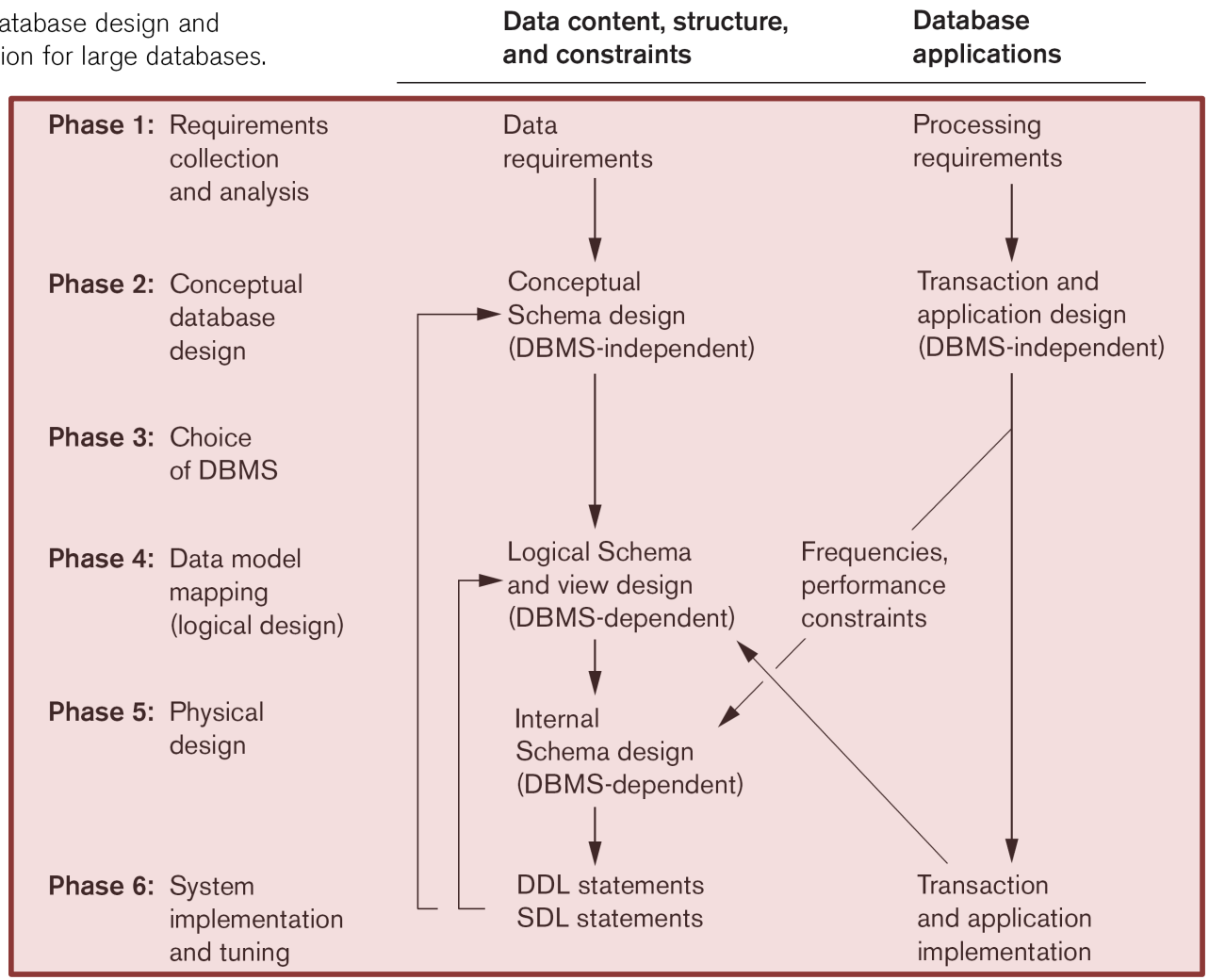


Outline

- Context
- Access Control
  - Strong password policies, 2FA
  - Discretionary, Mandatory
  - Least Privilege, Separate Privileges
- Attacks
  - SQL Injection
  - DoS (limit password length!)
  - Brute force password attempts (iCloud)
  - Internal vs. External (80% internal via Oracle)
  - Separate server, updates, audit logs
- Inference Control
- Encryption
  - Symmetric, Asymmetric, Hashing – tricky to get right!
  - Whole Database (and backups!), Communication
  - Sensitive Data, Password Storage

Database Design and Implementation Process

Figure 10.1
Phases of database design and implementation for large databases.



Guidelines

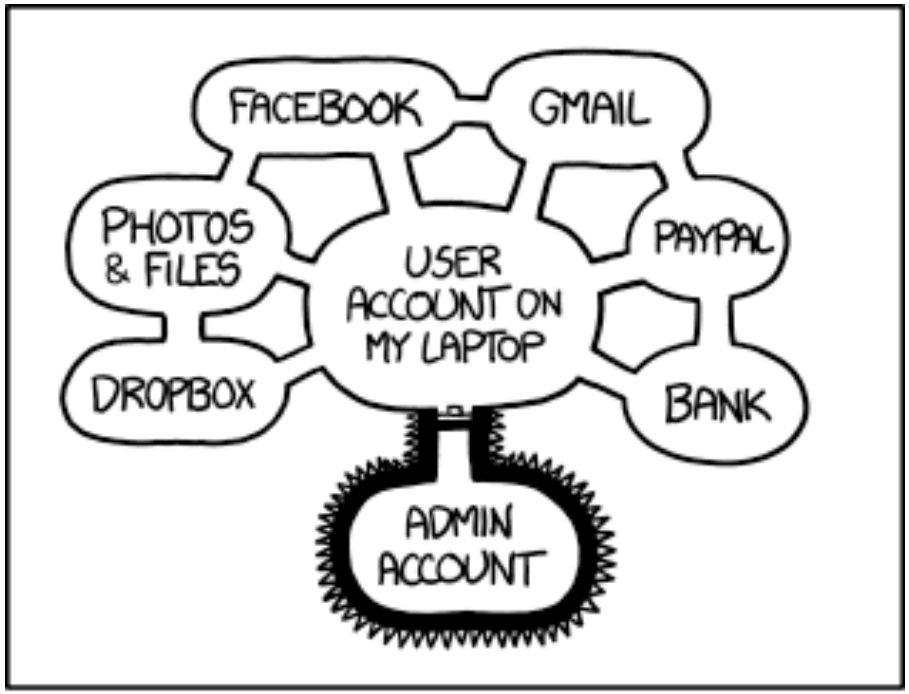
- Security as first-class citizen
  - *Early on security was an add-on, now it is everything*
- Security via depth
  - *Don't assume a firewall will save you*
- Design for failure
  - *What happens after a breach occurs?*
- Secure the weakest link
  - *Anything but the crypto!*
- Obscurity is not security
  - *Keys in binary stand out like sore thumbs*
  - *Stored procedures are not a cure for access control*

Access Control

- **Authentication**: who are you
  - Typically username + **secret**
    - Something you know (password)
    - Something you have (smart card/phone)
    - Something you are (fingerprint, iris)

- **Authorization**: what can you do

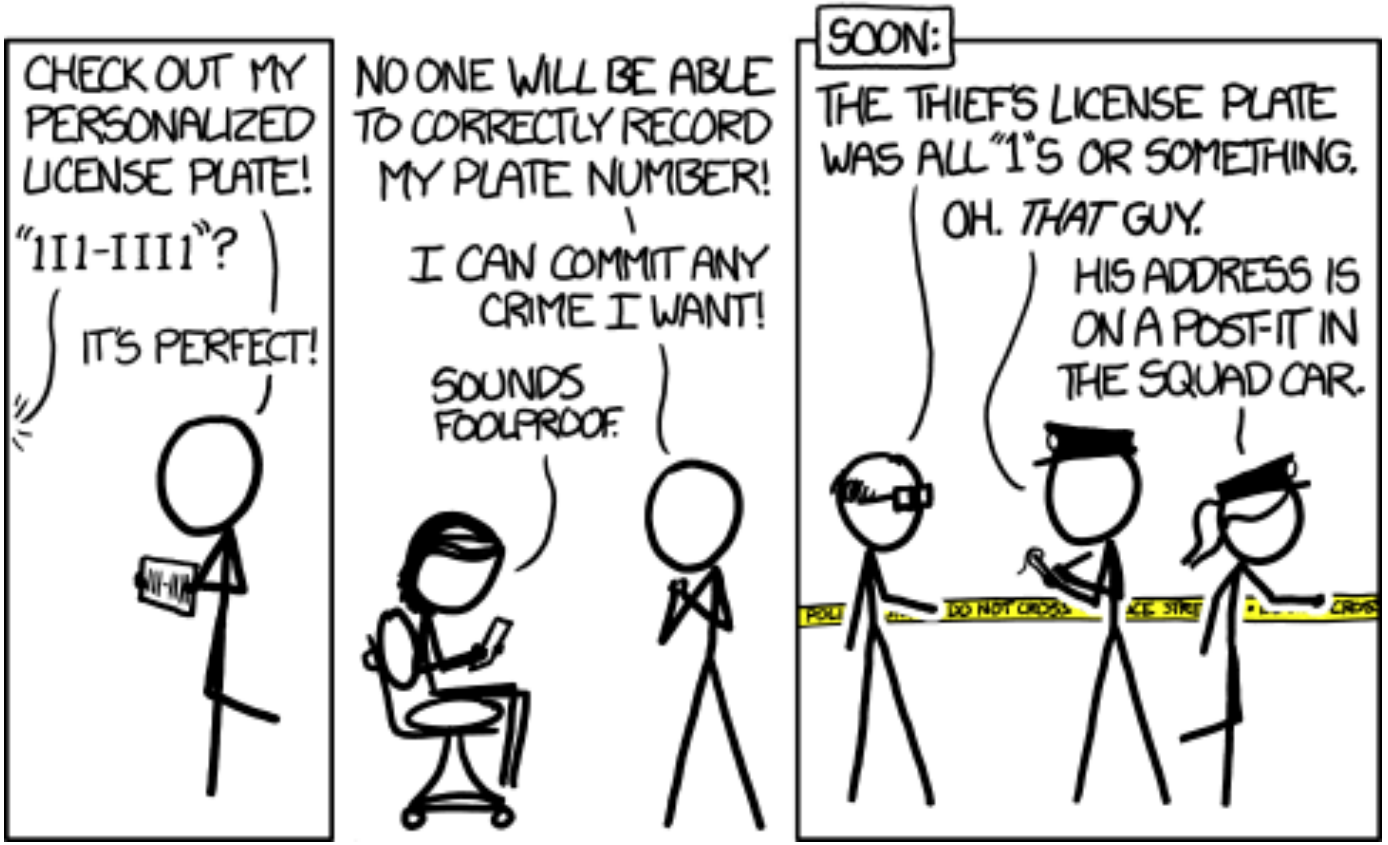
XKCD: Authorization



IF SOMEONE STEALS MY LAPTOP WHILE I'M LOGGED IN, THEY CAN READ MY EMAIL, TAKE MY MONEY, AND IMPERSONATE ME TO MY FRIENDS,

BUT AT LEAST THEY CAN'T INSTALL DRIVERS WITHOUT MY PERMISSION.

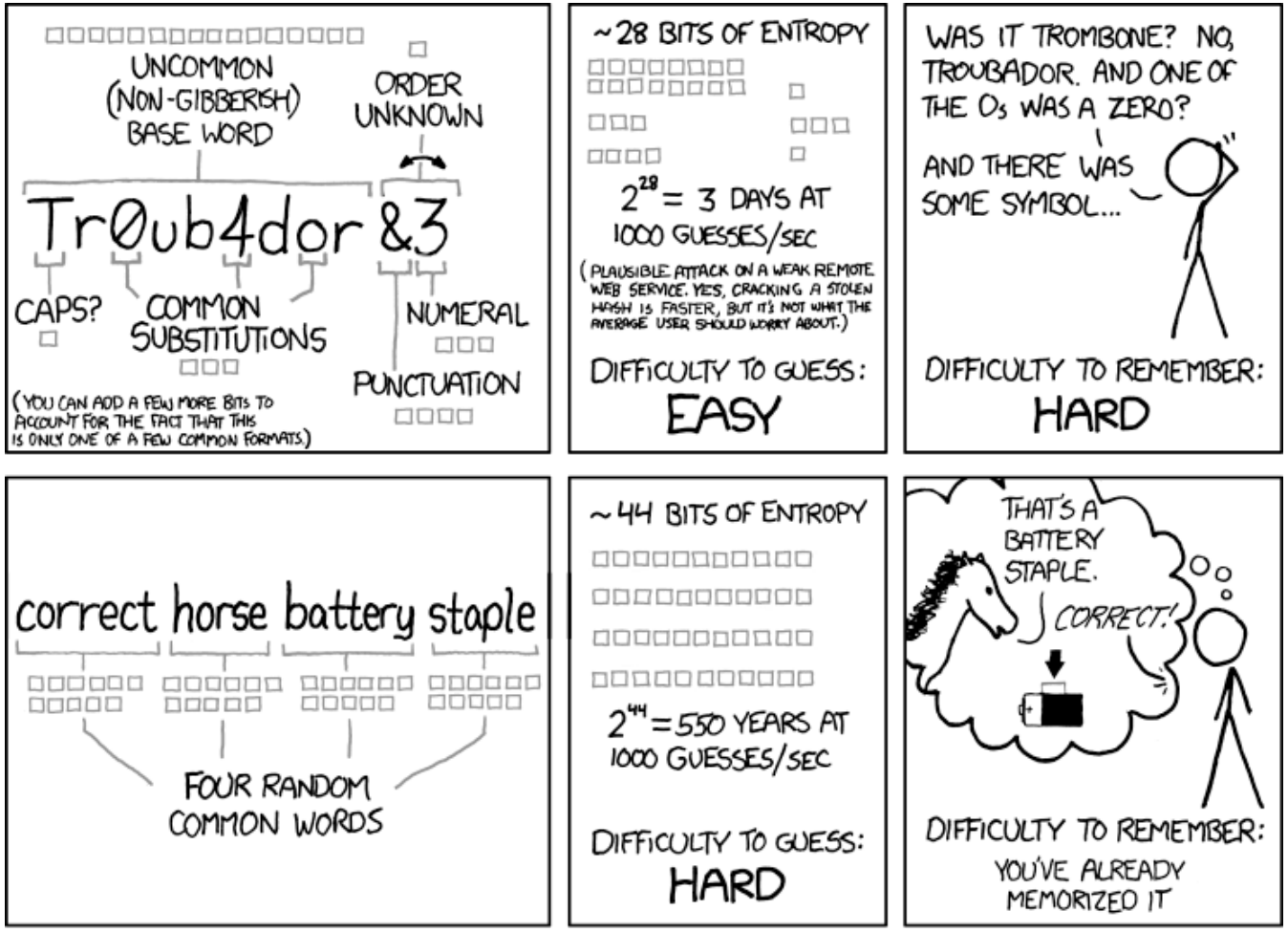
XCKD: License Plate



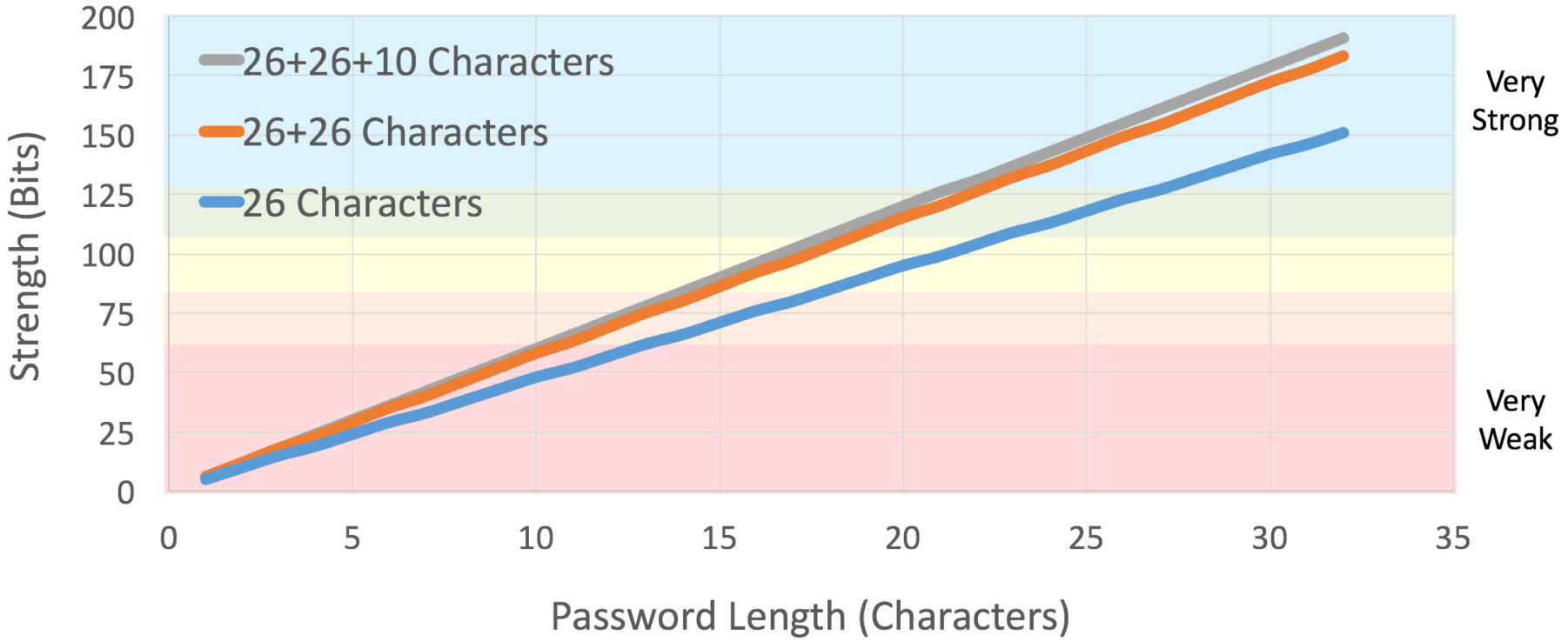
Authentication Policies

- Passwords
  - Enforce minimum length/complexity
    - Also maximum (more later w.r.t. DoS)
  - Consider not allowing common values
  - Goal: make guessing/cracking difficult
    - Cross-service
- Attempts
  - Enforce limits to avoid brute force (iCloud)
- 2 Factor Authentication (2FA)
  - Often infeasible
  - Implementation may weaken
    - e.g. Social engineering

XKCD: Password Strength



Random Passwords



But Passwords Are Not Random

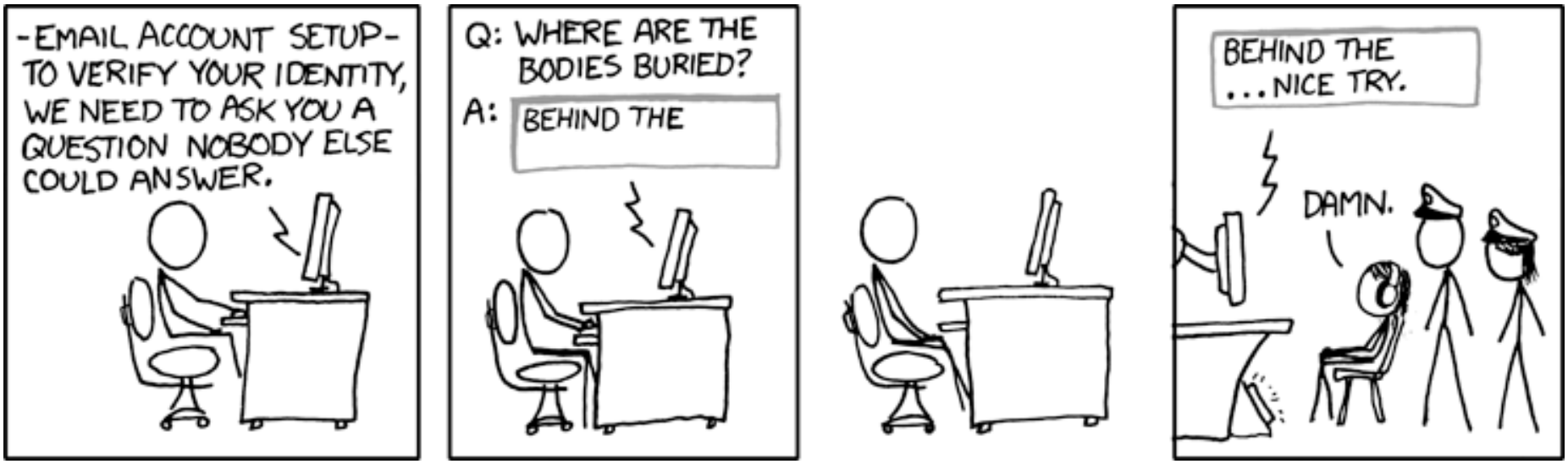
Top 25 most common passwords by year according to SplashData

Rank	2011[4]	2012[5]	2013[6]	2014[7]	2015[8]	2016[3]
1	password	password	123456	123456	123456	123456
2	123456	123456	password	password	password	password
3	12345678	12345678	12345678	12345	12345678	12345
4	qwerty	abc123	qwerty	12345678	qwerty	12345678
5	abc123	qwerty	abc123	qwerty	12345	football
6	monkey	monkey	123456789	123456789	123456789	qwerty
7	1234567	letmein	111111	1234	football	1234567890
8	letmein	dragon	1234567	baseball	1234	1234567
9	trustno1	111111	iloveyou	dragon	1234567	princess
10	dragon	baseball	adobe123[a]	football	baseball	1234
11	baseball	iloveyou	123123	1234567	welcome	login
12	111111	trustno1	admin	monkey	1234567890	welcome
13	iloveyou	1234567	1234567890	letmein	abc123	solo
14	master	sunshine	letmein	abc123	111111	abc123
15	sunshine	master	photoshop[a]	111111	1qaz2wsx	admin
16	ashley	123123	1234	mustang	dragon	121212
17	bailey	welcome	monkey	access	master	flower
18	passw0rd	shadow	shadow	shadow	monkey	passw0rd
19	shadow	ashley	sunshine	master	letmein	dragon
20	123123	football	12345	michael	login	sunshine
21	654321	jesus	password1	superman	princess	master
22	superman	michael	princess	696969	qwertyuiop	hottie
23	qazwsx	ninja	azerty	123123	solo	loveme
24	michael	mustang	trustno1	batman	passw0rd	zaq1zaq1
25	Football	password1	000000	trustno1	starwars	password1

Public Service Announcement

- Check: ';--have i been pwned? <**https://haveibeenpwned.com**>
  - User/e-mail
  - Services
  - Common passwords

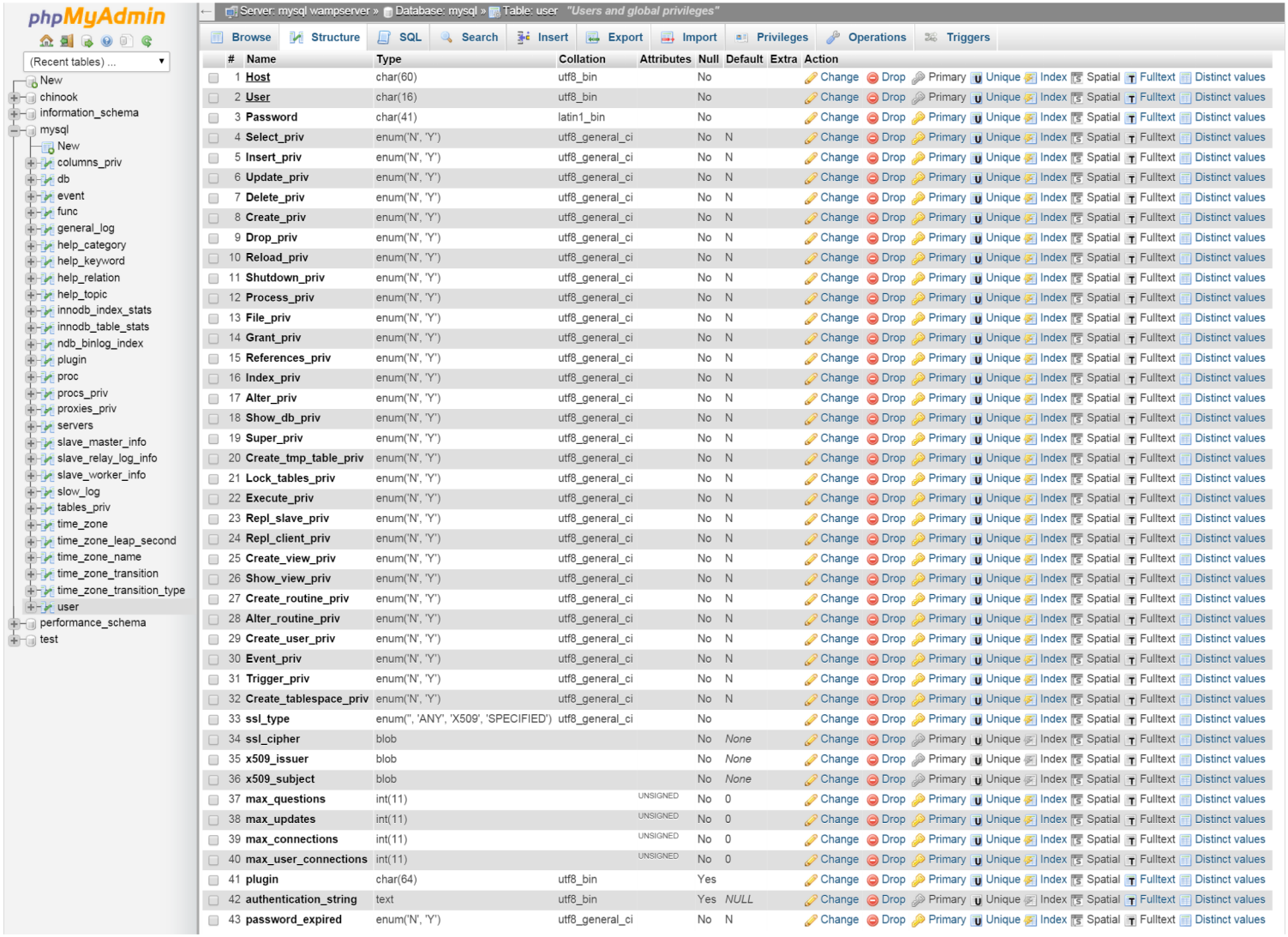
XKCD: Security Question



Discretionary Access Control

- Users **grant/revoke** privileges to other users
  - Starts with root/superuser/dba
  - with **`GRANT OPTION`**
- Privileges typically apply at multiple levels
  - Global, database, table, column
- Access matrix model
  - Users x Objects
- Fairly universal

MySQL (user)



#	Name	Type	Collation	Attributes	Null	Default	Extra	Action
1	Host	char(60)	utf8_bin		No			Change Drop Primary Unique Index Spatial Fulltext Distinct values
2	User	char(16)	utf8_bin		No			Change Drop Primary Unique Index Spatial Fulltext Distinct values
3	Password	char(41)	latin1_bin		No			Change Drop Primary Unique Index Spatial Fulltext Distinct values
4	Select_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
5	Insert_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
6	Update_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
7	Delete_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
8	Create_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
9	Drop_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
10	Reload_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
11	Shutdown_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
12	Process_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
13	File_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
14	Grant_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
15	References_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
16	Index_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
17	Alter_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
18	Show_db_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
19	Super_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
20	Create_tmp_table_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
21	Lock_tables_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
22	Execute_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
23	Repl_slave_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
24	Repl_client_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
25	Create_view_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
26	Show_view_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
27	Create_routine_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
28	Alter_routine_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
29	Create_user_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
30	Event_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
31	Trigger_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
32	Create_tablespace_priv	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values
33	ssl_type	enum('', 'ANY', 'X509', 'SPECIFIED')	utf8_general_ci		No			Change Drop Primary Unique Index Spatial Fulltext Distinct values
34	ssl_cipher	blob			No	*None*		Change Drop Primary Unique Index Spatial Fulltext Distinct values
35	x509_issuer	blob			No	*None*		Change Drop Primary Unique Index Spatial Fulltext Distinct values
36	x509_subject	blob			No	*None*		Change Drop Primary Unique Index Spatial Fulltext Distinct values
37	max_questions	int(11)		UNSIGNED	No	0		Change Drop Primary Unique Index Spatial Fulltext Distinct values
38	max_updates	int(11)		UNSIGNED	No	0		Change Drop Primary Unique Index Spatial Fulltext Distinct values
39	max_connections	int(11)		UNSIGNED	No	0		Change Drop Primary Unique Index Spatial Fulltext Distinct values
40	max_user_connections	int(11)		UNSIGNED	No	0		Change Drop Primary Unique Index Spatial Fulltext Distinct values
41	plugin	char(64)	utf8_bin		Yes			Change Drop Primary Unique Index Spatial Fulltext Distinct values
42	authentication_string	text	utf8_bin		Yes	*NULL*		Change Drop Primary Unique Index Spatial Fulltext Distinct values
43	password_expired	enum('N', 'Y')	utf8_general_ci		No	N		Change Drop Primary Unique Index Spatial Fulltext Distinct values

MySQL (db)

Server: mysql wampserver » Database: mysql » Table: db *"Database privileges"*

Browse | Structure | SQL | Search | Insert | Export

#	Name	Type	Collation	Attributes	Null	Default	Extr
1	Host	char(60)	utf8_bin		No		
2	Db	char(64)	utf8_bin		No		
3	User	char(16)	utf8_bin		No		
4	Select_priv	enum('N', 'Y')	utf8_general_ci		No	N	
5	Insert_priv	enum('N', 'Y')	utf8_general_ci		No	N	
6	Update_priv	enum('N', 'Y')	utf8_general_ci		No	N	
7	Delete_priv	enum('N', 'Y')	utf8_general_ci		No	N	
8	Create_priv	enum('N', 'Y')	utf8_general_ci		No	N	
9	Drop_priv	enum('N', 'Y')	utf8_general_ci		No	N	
10	Grant_priv	enum('N', 'Y')	utf8_general_ci		No	N	
11	References_priv	enum('N', 'Y')	utf8_general_ci		No	N	
12	Index_priv	enum('N', 'Y')	utf8_general_ci		No	N	
13	Alter_priv	enum('N', 'Y')	utf8_general_ci		No	N	
14	Create_tmp_table_priv	enum('N', 'Y')	utf8_general_ci		No	N	
15	Lock_tables_priv	enum('N', 'Y')	utf8_general_ci		No	N	
16	Create_view_priv	enum('N', 'Y')	utf8_general_ci		No	N	
17	Show_view_priv	enum('N', 'Y')	utf8_general_ci		No	N	
18	Create_routine_priv	enum('N', 'Y')	utf8_general_ci		No	N	
19	Alter_routine_priv	enum('N', 'Y')	utf8_general_ci		No	N	
20	Execute_priv	enum('N', 'Y')	utf8_general_ci		No	N	
21	Event_priv	enum('N', 'Y')	utf8_general_ci		No	N	
22	Trigger_priv	enum('N', 'Y')	utf8_general_ci		No	N	

MySQL (tables_priv)

Server: mysql wampserver » Database: mysql » Table: tables_priv *"Table privileges"*

Browse | Structure | SQL | Search | Insert | Export | Import | Privileges | Operations | Triggers

#	Name	Type	Collation	Attributes	Null	Default	Extra
1	Host	char(60)	utf8_bin		No		
2	Db	char(64)	utf8_bin		No		
3	User	char(16)	utf8_bin		No		
4	Table_name	char(64)	utf8_bin		No		
5	Grantor	char(77)	utf8_bin		No		
6	Timestamp	timestamp		on update CURRENT_TIMESTAMP	No	CURRENT_TIMESTAMP	ON UPDATE CURRENT_TIMESTAMP
7	Table_priv	set('Select', 'Insert', 'Update', 'Delete', 'Creat	utf8_general_ci		No		
8	Column_priv	set('Select', 'Insert', 'Update', 'References')	utf8_general_ci		No		

MySQL (columns_priv)

Server: mysql wampserver » Database: mysql » Table: columns_priv *"Column privileges"*

Browse | Structure | SQL | Search | Insert | Export | Import | Privileges | Operations | Triggers

#	Name	Type	Collation	Attributes	Null	Default	Extra
1	Host	char(60)	utf8_bin		No		
2	Db	char(64)	utf8_bin		No		
3	User	char(16)	utf8_bin		No		
4	Table_name	char(64)	utf8_bin		No		
5	Column_name	char(64)	utf8_bin		No		
6	Timestamp	timestamp		on update CURRENT_TIMESTAMP	No	CURRENT_TIMESTAMP	ON UPDATE CURRENT_TIMESTA
7	Column_priv	set('Select', 'Insert', 'Update', 'References')	utf8_general_ci		No		

Mandatory Access Control

- Objects are classified with security levels
- Users are afforded security clearance
- Government model, not typically supported

Privilege Policies

- Principle of least privilege
- Privilege separation
  - Multiple users, each with least privilege
- Abuse
  - Unauthorized
    - Mitigate escalation attacks
  - Authorized
    - Teachers changing grades
    - Firing a DBA

SQL Injection

SQL manipulation for nefarious purpose

Method
- String manipulation
  - Parameters, function calls
- Code injection (e.g. buffer overflow)

Goals
- Fingerprinting
  - Learn about service via version, configuration
- DoS
- Bypass authentication/privilege escalation
- Remote execution

Protection
- Parameterized statements
- Filter input
- Limit use of custom functions

SQL Injection Examples

Original query:

```
"SELECT name, description
 FROM items
 WHERE id='" + req.args.get('id', '') + "'"
```

Result after injection:

```
SELECT name, description
FROM items
WHERE id='12'
UNION
SELECT username, passwd FROM users;--';
```

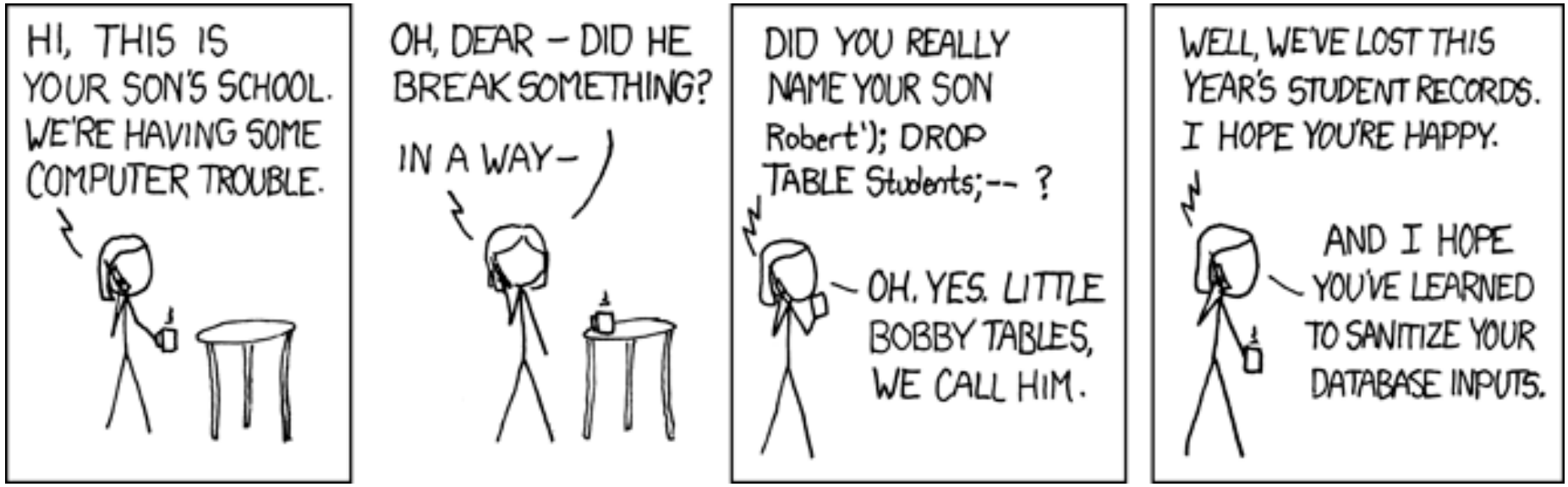
Original query:

```
"UPDATE users
 SET passwd='" + req.args.get('pw', '') + "'
 WHERE user='" + req.args.get('user', '') + "'"
```

Result after injection:

```
UPDATE users
SET passwd='...'
WHERE user='dude' OR 1=1;--';
```

XKCD: Exploits of a Mom



Denial of Service (DoS)

Any exposed interface

- Failed login
  - Lock out users
  - Resource utilization via long password verification
- Complex queries

Mitigation

- Resource limits
- Patching
- Monitoring

XCKD: CIA


HACKERS BRIEFLY TOOK DOWN THE WEBSITE OF THE CIA YESTERDAY...
WHAT PEOPLE HEAR:
SOMEONE HACKED INTO THE COMPUTERS OF THE CIA!!
WHAT COMPUTER EXPERTS HEAR:
SOMEONE TORE DOWN A POSTER HUNG UP BY THE CIA!!

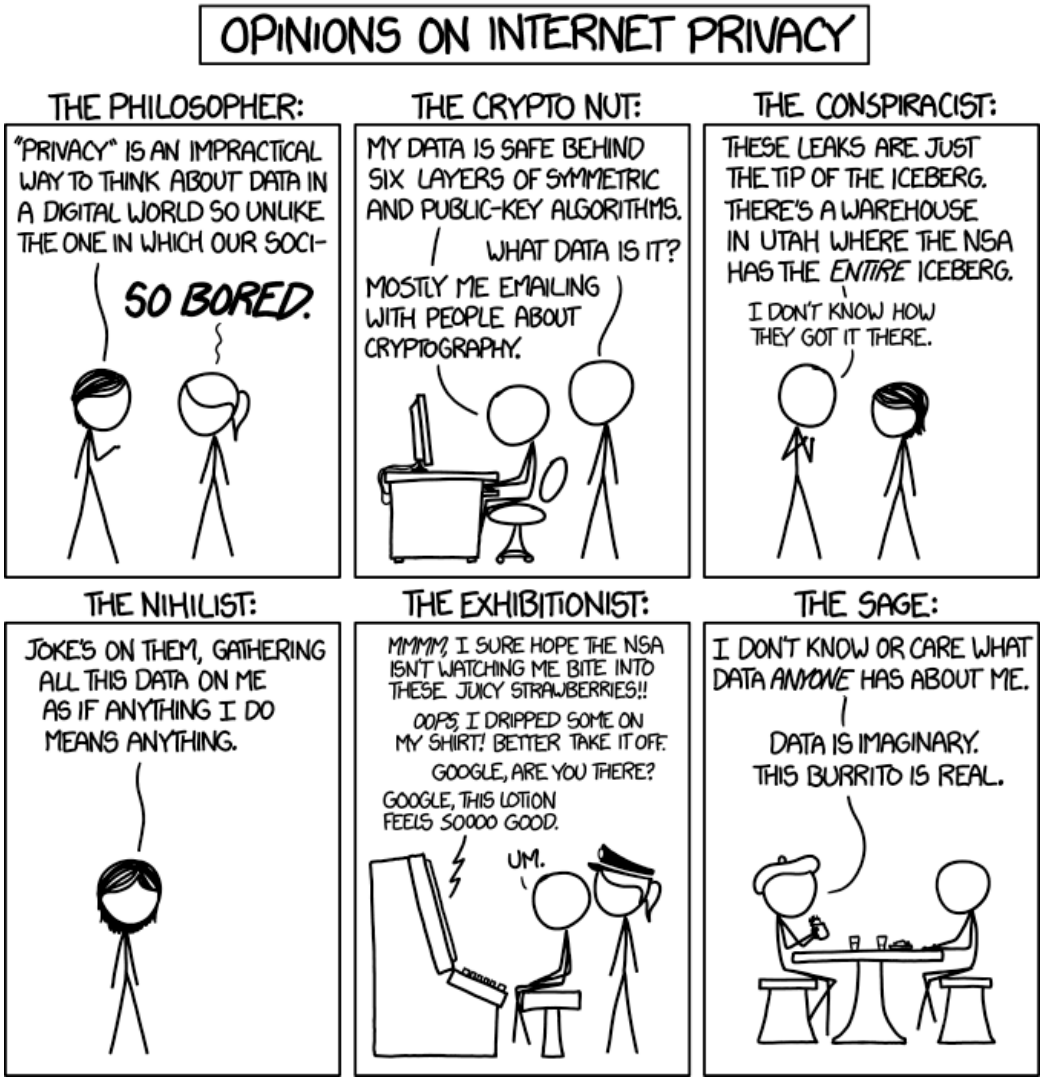
Protection

- Protect against internal attacks
  - Oracle: up to 80% of data loss
- Isolate DBMS
  - Separate machine, VM
- Regular patching policies
- Audit logs

Inferential Security

- Relevant when offering parameterized access to aggregate data
  - But must protect sensitive individual data!
- Prior knowledge and/or clever exploration might yield queries that reveal private information
  - Find “average” salary of <insert conditions that identify single individual>
- Techniques
  - Minimum result set size threshold
  - Added noise
  - Group partitioning

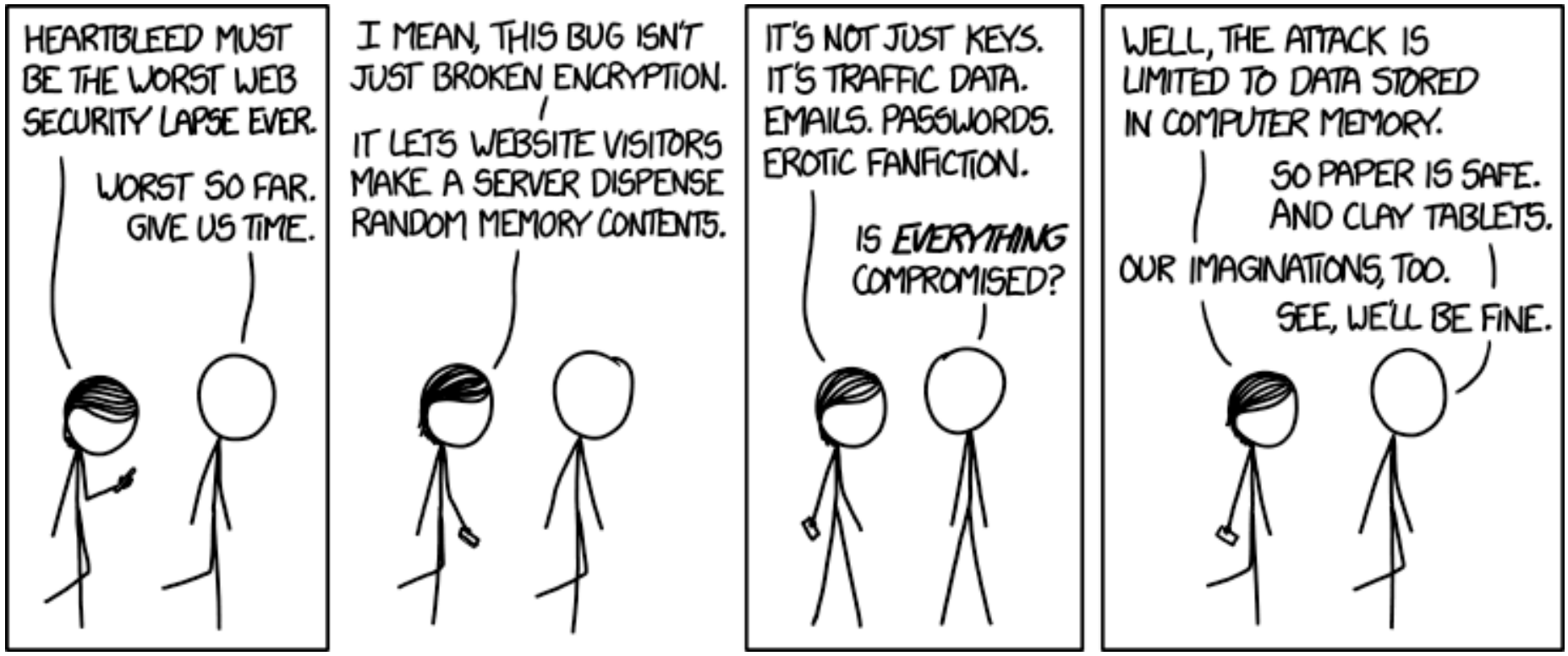
XKCD: Privacy Opinions



Encryption

- Symmetric
  - Single key encrypts/decrypts
- Asymmetric
  - 2 Keys: public encryption, private decryption
- Hashing
  - No decryption
- Encryption theory is solid, implementation is tricky
  - High-quality randomness
  - Bug-free code

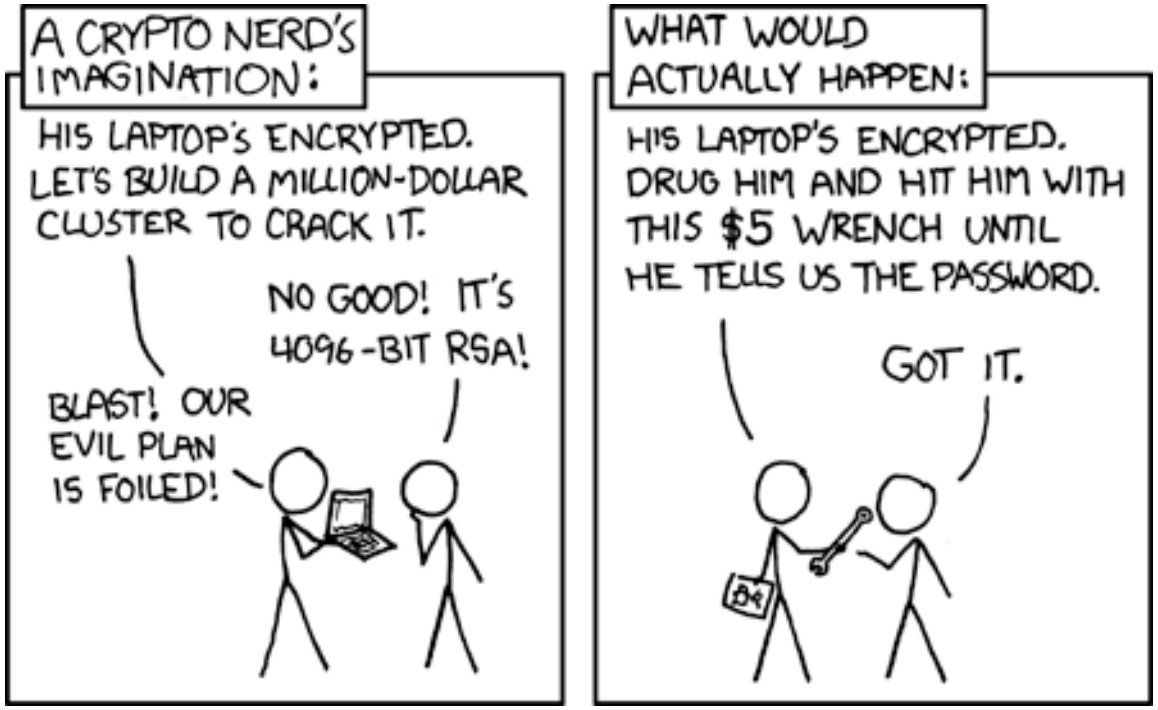
XCKD: Heartbleed



Basics

- Encrypt database files
  - Including backups!
  - Native or 3rd-party wrapper
  - Can be difficult to implement while being resilient to restarts, high-performance
- Encrypt application communication
  - Use https, SSH
  - NOT http, telnet/FTP

XCKD: Security



Sensitive Data

- When dealing with sensitive data, always consider how it needs to be used
- If only verification (e.g. password), hash
- If usage, encrypt
  - NOT clear text CC entry
  - Better: encrypt CC
  - Best: encrypt last 4 of CC + use private payment processing server

Password Storage

- Many applications require authentication
  - Website, mobile
- Sometimes you can use external authentication
  - LDAP, OAuth 2.0 via Google or Facebook
- Sometimes you need your own system
  - So now we consider how to securely store authentication secrets in a database

Attacker Goals and Threat Model

- Assume we have a system storing usernames and passwords
- The attacker has access to the password database/file

Database

User	Password
cbw	p4ssW0rd
sandi	puppies
amislove	3spr3ss0

I wanna login to those user accounts!

Cracked Passwords

User	Password
cbw	p4ssW0rd
sandi	puppies
amislove	3spr3ss0

Checking Passwords

- System must validate passwords provided by users
- Thus, passwords must be stored somewhere
- Basic storage: plain text

password.txt

cbw	p4ssw0rd
sandi	i heart doggies
amislove	93Gd9#jv*0x3N
bob	security

Problem: Password File Theft

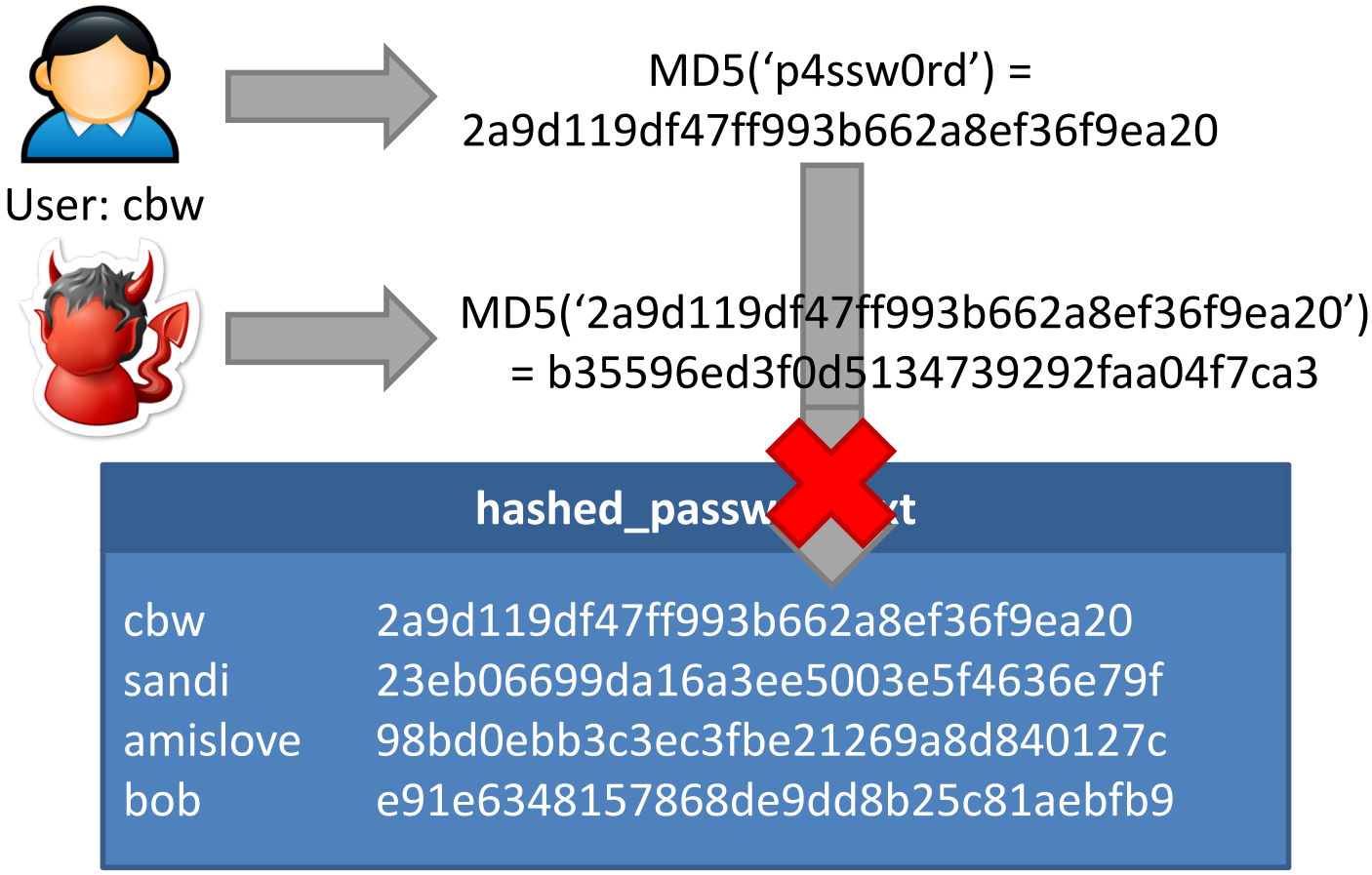
- Attackers often compromise systems
- They may be able to steal the password file
  - Linux: /etc/shadow
  - Windows: c:\windows\system32\config\sam
- If the passwords are plain text, what happens?
  - The attacker can now log-in as any user, including root/administrator
  - The attacker can/will use them elsewhere >:(
- **Passwords should never be stored in plain text**

Hashed Passwords

- Key idea: store encrypted versions of passwords
  - Use one-way cryptographic hash functions
  - Examples: MD5, SHA1, SHA256, SHA512, bcrypt, PBKDF2, scrypt

- Cryptographic hash function transform input data into scrambled output data
  - Deterministic: hash(A) = hash(A)
  - High entropy:
    - MD5('security') = e91e6348157868de9dd8b25c81aebfb9
    - MD5('security1') = 8632c375e9eba096df51844a5a43ae93
    - MD5('Security') = 2fae32629d4ef4fc6341f1751b405e45
  - Collision resistant
    - Locating A' such that hash(A) = hash(A') takes a long time (hopefully)
    - Example: 221 tries for md5

Hashed Password Example



Attacking Password Hashes

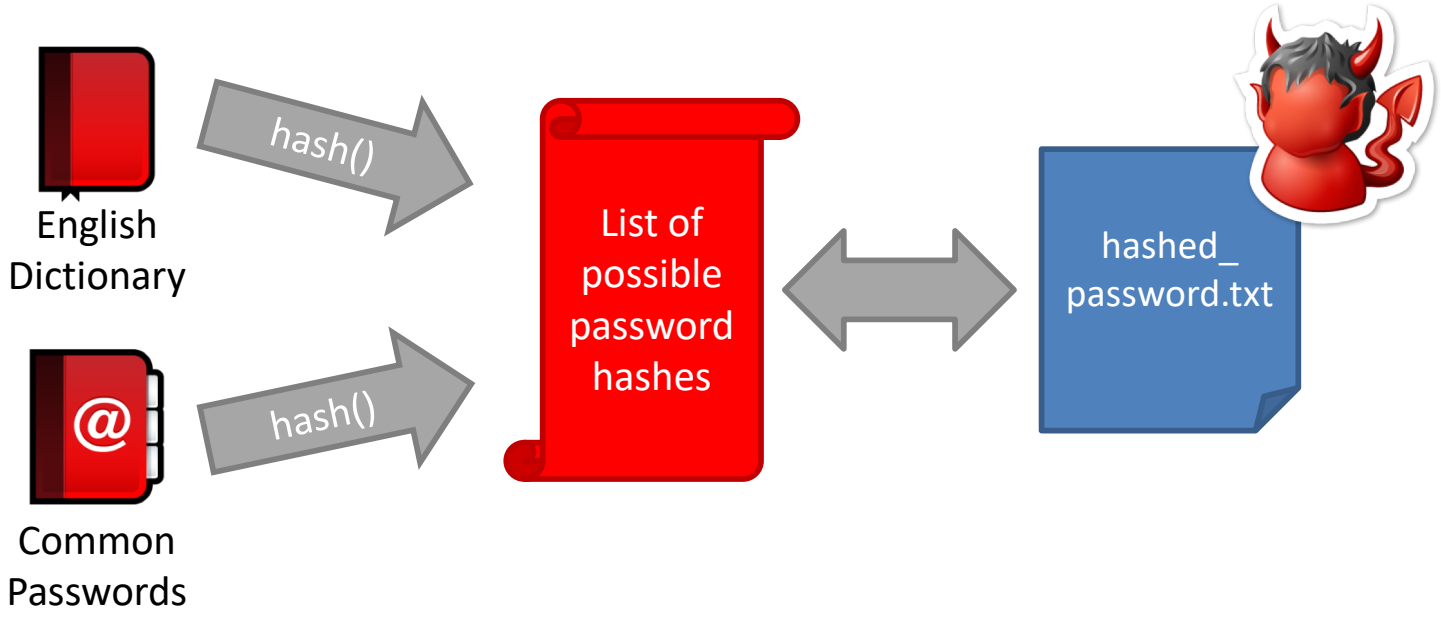
- Recall: cryptographic hashes are collision resistant
  - Locating A' such that hash(A) = hash(A') takes a long time (hopefully)
- Are hashed password secure from cracking?
  - No!
- Problem: users choose poor passwords
  - Most common passwords: 123456, password
  - Username: cbw, Password: cbw
- Weak passwords enable dictionary attacks

Remember: Passwords Are Not Random

Top 25 most common passwords by year according to SplashData

Rank	2011[4]	2012[5]	2013[6]	2014[7]	2015[8]	2016[3]
1	password	password	123456	123456	123456	123456
2	123456	123456	password	password	password	password
3	12345678	12345678	12345678	12345	12345678	12345
4	qwerty	abc123	qwerty	12345678	qwerty	12345678
5	abc123	qwerty	abc123	qwerty	12345	football
6	monkey	monkey	123456789	123456789	123456789	qwerty
7	1234567	letmein	111111	1234	football	1234567890
8	letmein	dragon	1234567	baseball	1234	1234567
9	trustno1	111111	iloveyou	dragon	1234567	princess
10	dragon	baseball	adobe123[a]	football	baseball	1234
11	baseball	iloveyou	123123	1234567	welcome	login
12	111111	trustno1	admin	monkey	1234567890	welcome
13	iloveyou	1234567	1234567890	letmein	abc123	solo
14	master	sunshine	letmein	abc123	111111	abc123
15	sunshine	master	photoshop[a]	111111	1qaz2wsx	admin
16	ashley	123123	1234	mustang	dragon	121212
17	bailey	welcome	monkey	access	master	flower
18	passw0rd	shadow	shadow	shadow	monkey	passw0rd
19	shadow	ashley	sunshine	master	letmein	dragon
20	123123	football	12345	michael	login	sunshine
21	654321	jesus	password1	superman	princess	master
22	superman	michael	princess	696969	qwertyuiop	hottie
23	qazwsx	ninja	azerty	123123	solo	loveme
24	michael	mustang	trustno1	batman	passw0rd	zaq1zaq1
25	Football	password1	000000	trustno1	starwars	password1

Dictionary Attacks



- Common for 60-70% of hashed passwords to be cracked in <24 hours

Hardening Password Hashes

- Key problem: cryptographic hashes are deterministic
  - hash('p4ssw0rd') = hash('p4ssw0rd')
  - This enables attackers to build lists of hashes

- Solution: make each password hash unique
  - Add a salt to each password before hashing
  - hash(salt + password) = password hash
  - Each user has a unique, random salt
  - Salts can be stores in plain text

Example Salted Hashes

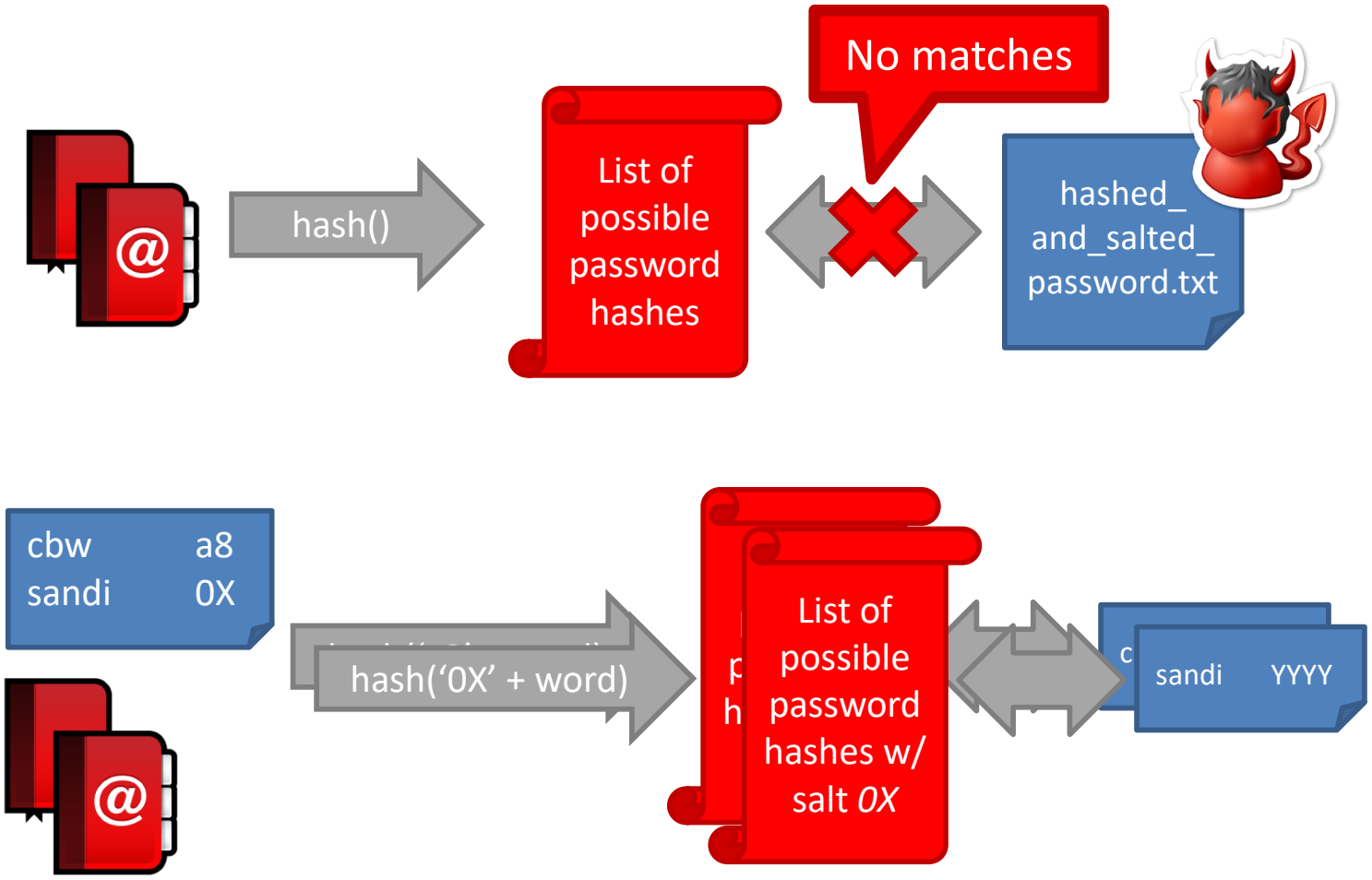
hashed_password.txt

cbw	2a9d119df47ff993b662a8ef36f9ea20
sandi	23eb06699da16a3ee5003e5f4636e79f
amislove	98bd0ebb3c3ec3fbe21269a8d840127c
bob	e91e6348157868de9dd8b25c81aebfb9

hashed_and_salted_password.txt

cbw	a8	af19c842f0c781ad726de7aba439b033
sandi	0X	67710c2c2797441efb8501f063d42fb6
amislove	hz	9d03e1f28d39ab373c59c7bb338d0095
bob	K@	479a6d9e59707af4bb2c618fed89c245

Attacking Salted Passwords



Breaking Hashed Passwords

- Stored passwords should always be salted
  - Forces the attacker to brute-force each password individually

- Problem: it is now possible to compute hashes very quickly
  - GPU computing: hundreds of small CPU cores
  - nVidia GeForce GTX Titan Z: 5,760 cores
  - GPUs can be rented from the cloud very cheaply
    - 2x GPUs for $0.65 per hour (2014 prices)

Examples of Hashing Speed

- A modern x86 server can hash all possible 6 character long passwords in 3.5 hours
  - Upper and lowercase letters, numbers, symbols
  - (26+26+10+32)6 = 690 billion combinations
- A modern GPU can do the same thing in 16 minutes
- Most users use (slightly permuted) dictionary words, no symbols
  - Predictability makes cracking much faster
  - Lowercase + numbers → (26+10)6 = 2B combinations

Hardening Salted Passwords

- Problem: typical hashing algorithms are too fast
  - Enables GPUs to brute-force passwords
- Old solution: hash the password multiple times
  - Known as **key stretching**
  - Example: crypt used 25 rounds of DES
- New solution: use hash functions that are designed to be slow
  - Examples: bcrypt, PBKDF2, scrypt
  - These algorithms include a work factor that increases the time complexity of the calculation
  - scrypt also requires a large amount of memory to compute, further complicating brute-force attacks

bcrypt Example

- Python example; install the **`bcrypt`** package

```
[cbw@ativ9 ~] python
>>> import bcrypt
>>> password = "my super secret password"
>>> fast_hashed = bcrypt.hashpw(password, bcrypt.gensalt(0))
>>> slow_hashed = bcrypt.hashpw(password, bcrypt.gensalt(12))
>>> pw_from_user = raw_input("Enter your password:")
>>> if bcrypt.hashpw(pw_from_user, slow_hashed) == slow_hashed:
...         print "It matches! You may enter the system"
...   else:
...         print "No match. You may not proceed"
```

Work factor

Dealing With Breaches

- Suppose you build an extremely secure password storage system
  - All passwords are salted and hashed by a high-work factor function
- It is still possible for a dedicated attacker to steal and crack passwords
  - Given enough time and money, anything is possible
  - E.g. The NSA
- Question: is there a principled way to detect password breaches?

Honeywords

- Key idea: store multiple salted/hashed passwords for each user
  - As usual, users create a single password and use it to login
  - User is unaware that additional honeywords are stored with their account
- Implement a honeyserver that stores the index of the correct password for each user
  - Honeyserver is logically and physically separate from the password database
  - Silently checks that users are logging in with true passwords, not honeywords
- What happens after a data breach?
  - Attacker dumps the user/password database…
  - But the attacker doesn't know which passwords are honeywords
  - Attacker cracks all passwords and uses them to login to accounts
  - If the attacker logs-in with a honeyword, the honeyserver raises an alert!

Honeywords Example

cbw

SHA512("fl" | "p4ssW0rd") → bHDJ8l

Cracked Passwords

User	PW 1	PW 2	PW 3
cbw	123456	p4ssW0rd	Turtles!
sandi	puppies	iloveyou	blizzard
amislove	coff33	3spr3ss0	qwerty

Database

User	Salt 1	H(PW 1)	Salt 2	H(PW 2)	Salt 3	H(PW 3)
cbw	aB	y4DvF7	fl	bHDJ8l	52	Puu2s7
sandi	0x	plDS4F	K2	R/p3Y8	8W	S8x4Gk
amislove	9j	0F3g5H	/s	03d5jW	cV	1sRbJ5

Honeyserver

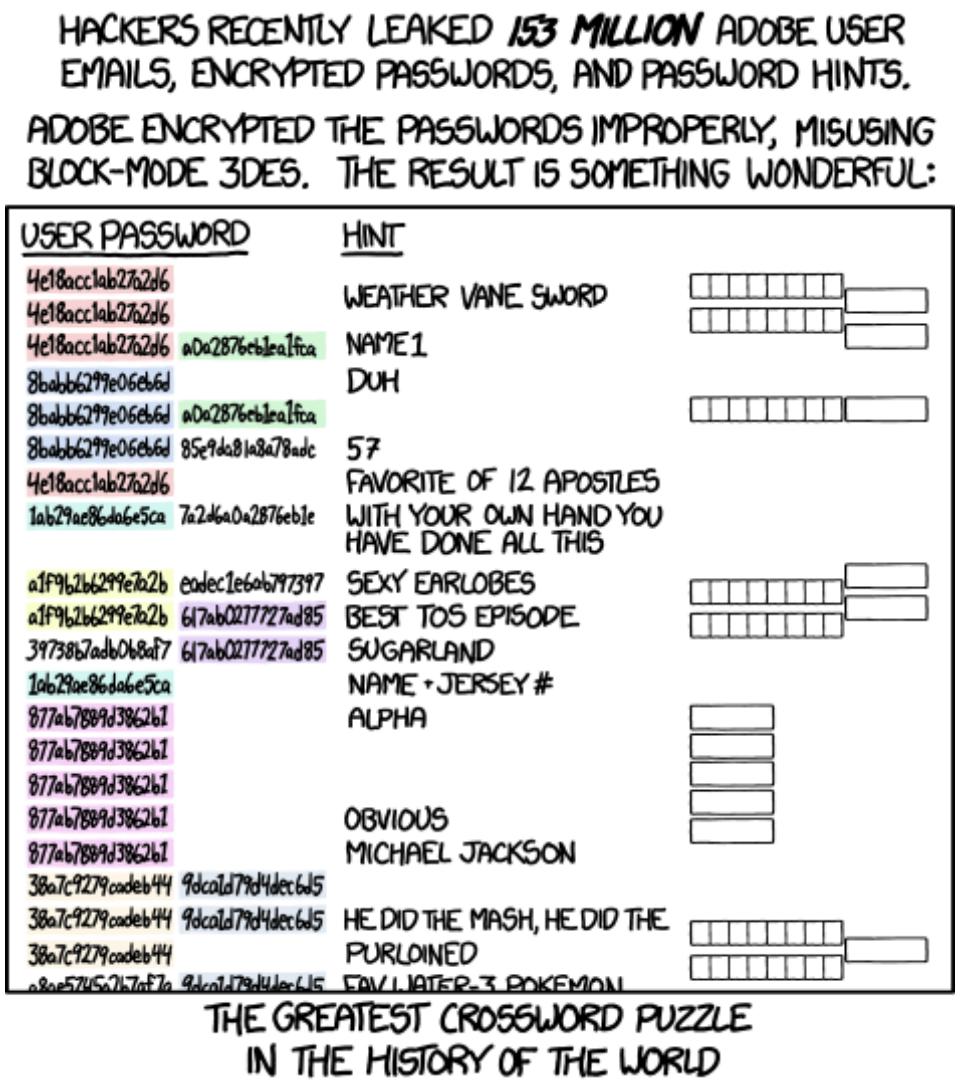
User	Index
cbw	2
sandi	3
amislove	1

Password Storage Summary

- Never store passwords in plain text
  - Always salt and hash passwords before storing them
- Use modern hash functions with a high work factor (e.g. avoid md5)
- Implement honeywords to detect breaches

- These rules apply to any system that needs to authenticate users
  - Operating systems, websites, etc.

XCKD: Encryptic



Summary

- When dealing with database applications, security needs to be a first-class citizen, considered at all levels, preparing for failure (the weakest link!)
  - Obscurity ≠ Security
- We covered issues/best practices related to authentication/authorization, common attacks, inference control, and encryption

XKCD: Password Reuse