

CSE 484 / CSE M 584: Computer Security and Privacy

Cryptography

[MACs and Hash Functions]

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Franziska (Franzi) Roesner

franzi@cs.washington.edu

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Admin

- Additional office hours scheduled
 - 12:30-1:30pm on Fridays
 - A single Zoom room for the whole 12:30-2:30pm timeslot

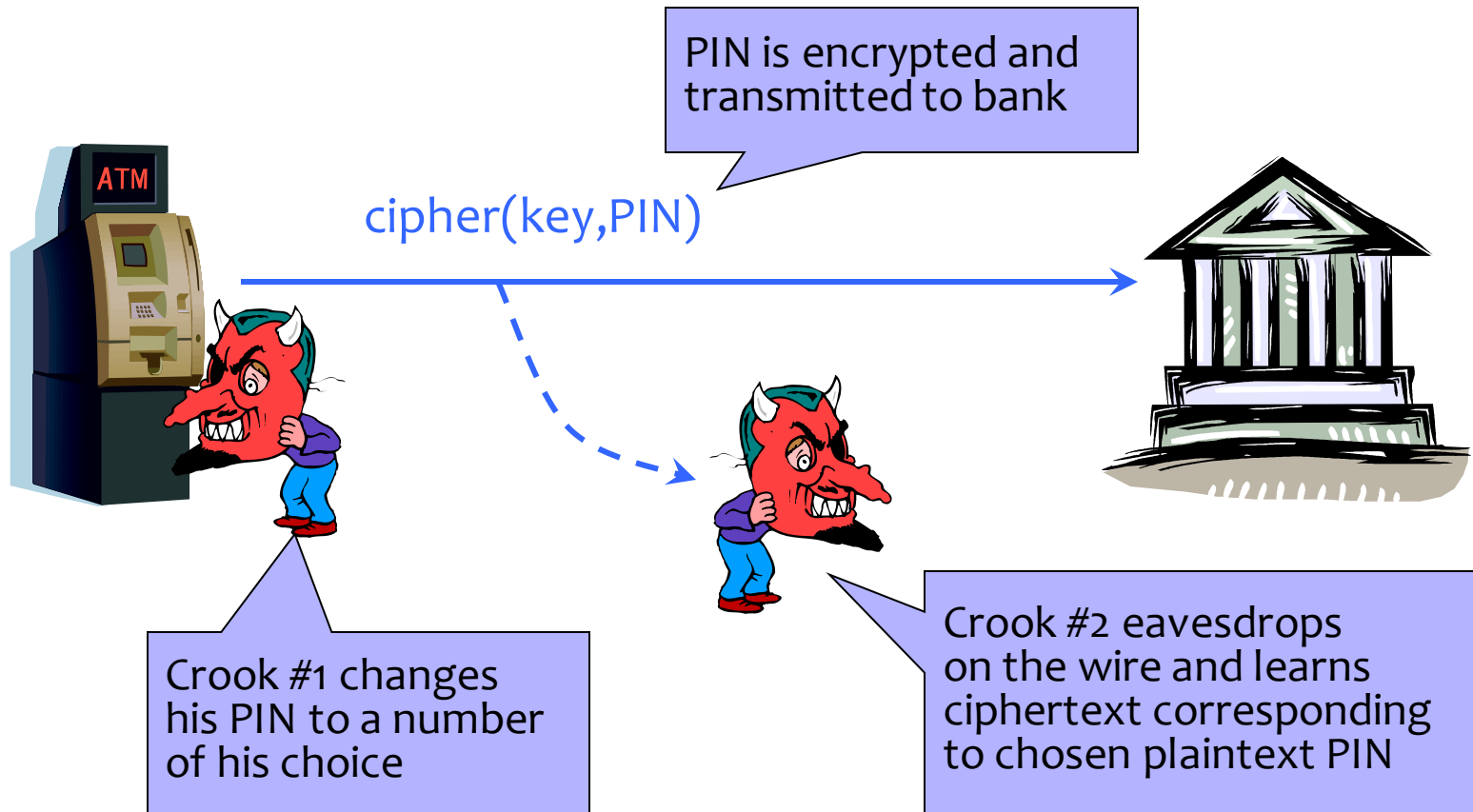
When is an Encryption Scheme “Secure”?

- Hard to recover the key?
 - What if attacker can learn plaintext without learning the key?
- Hard to recover plaintext from ciphertext?
 - What if attacker learns some bits or some function of bits?

How Can a Cipher Be Attacked?

- Attackers knows ciphertext and encryption algthm
 - What else does the attacker know? Depends on the application in which the cipher is used!

Chosen Plaintext Attack



... repeat for any PIN value

How Can a Cipher Be Attacked?

- Attackers knows ciphertext and encryption alghm
 - What else does the attacker know? Depends on the application in which the cipher is used!
- Ciphertext-only attack
- KPA: Known-plaintext attack (stronger)
 - Knows some plaintext-ciphertext pairs
- CPA: Chosen-plaintext attack (even stronger)
 - Can obtain ciphertext for any plaintext of his choice
- CCA: Chosen-ciphertext attack (very strong)
 - Can decrypt any ciphertext except the target

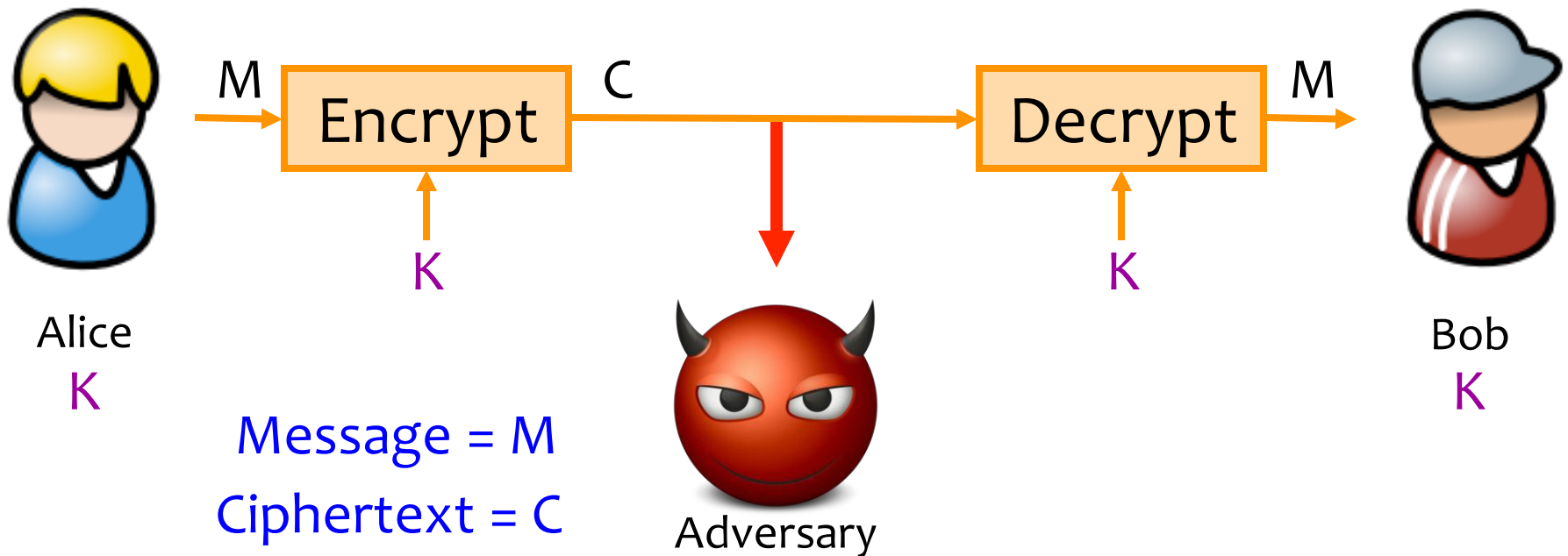
Very Informal Intuition

Minimum security requirement for a modern encryption scheme

- Security against chosen-plaintext attack (CPA)
 - Ciphertext leaks no information about the plaintext
 - Even if the attacker correctly guesses the plaintext, he cannot verify his guess
 - Every ciphertext is unique, encrypting same message twice produces completely different ciphertexts
 - Implication: encryption must be randomized or stateful
- Security against chosen-ciphertext attack (CCA)
 - Integrity protection – it is not possible to change the plaintext by modifying the ciphertext

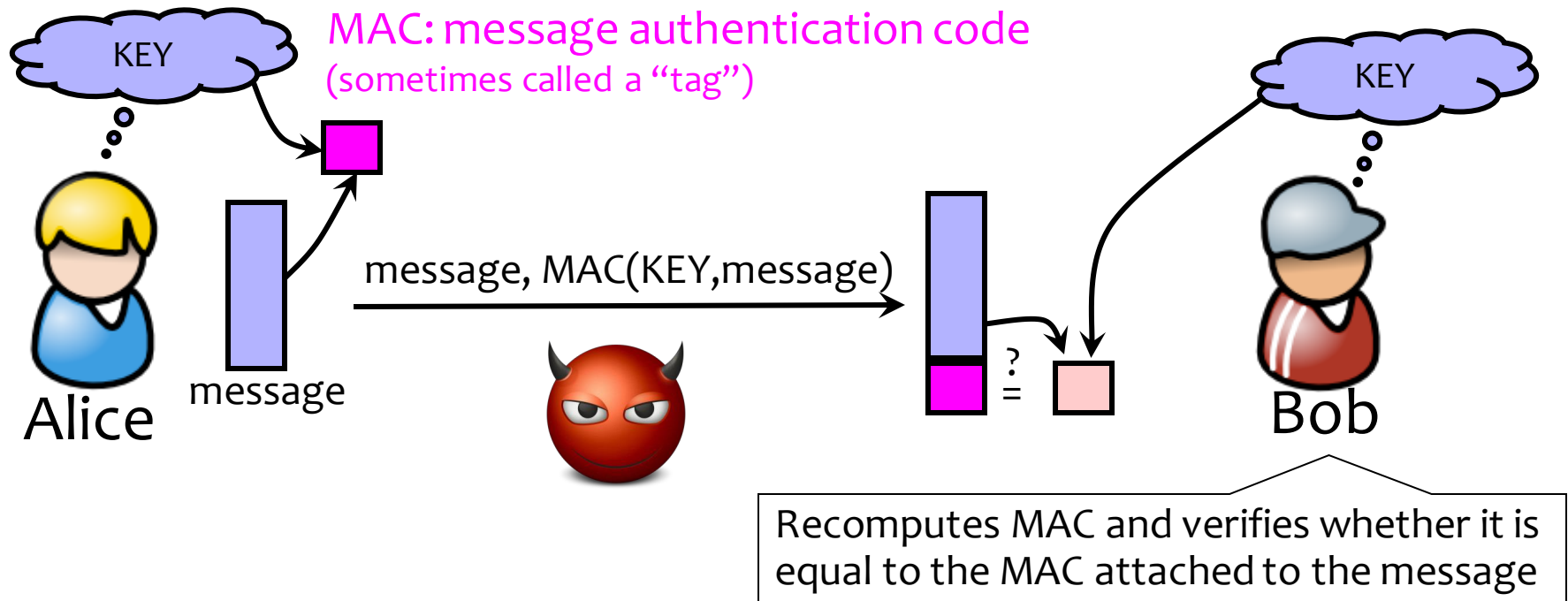
So Far: Achieving Privacy

Encryption schemes: A tool for protecting **privacy**.



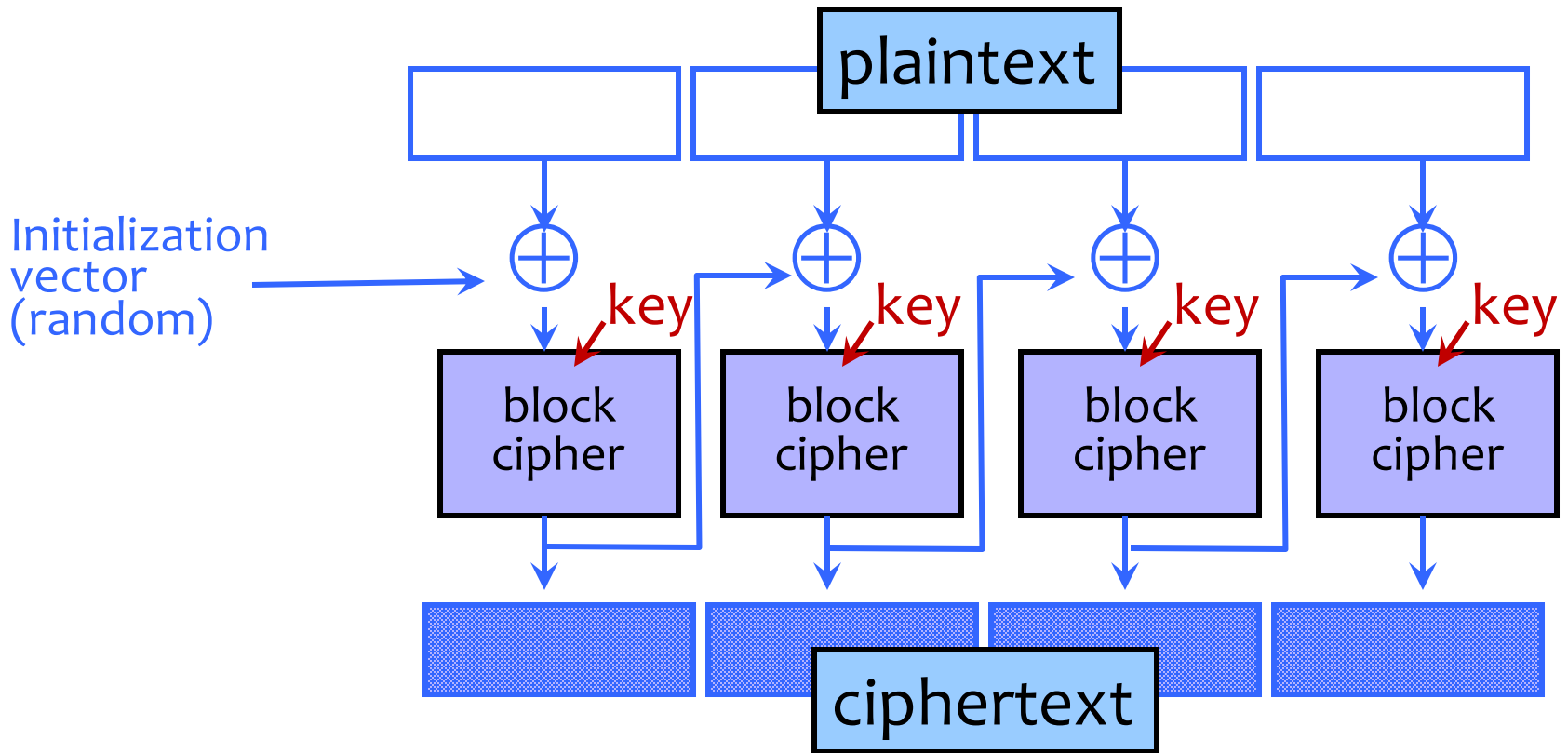
Now: Achieving Integrity

Message authentication schemes: A tool for protecting integrity.



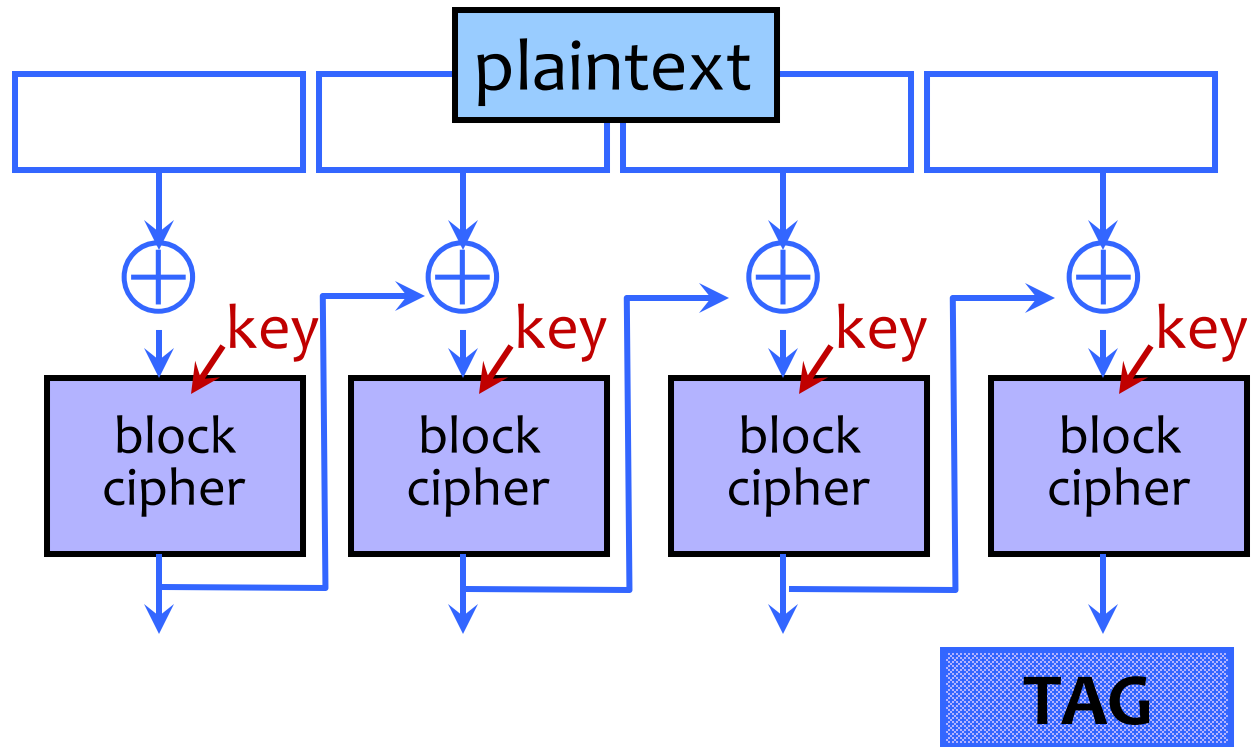
Integrity and authentication: only someone who knows KEY can compute correct MAC for a given message.

Reminder: CBC Mode Encryption



- Identical blocks of plaintext encrypted differently
- Last cipherblock depends on entire plaintext
 - Still does not guarantee integrity

CBC-MAC



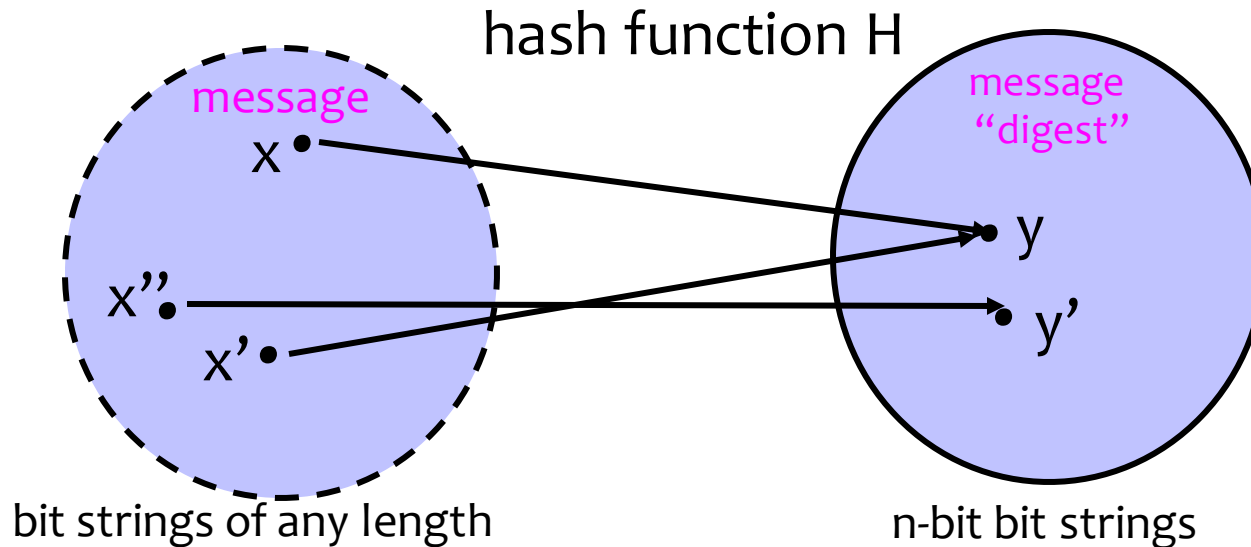
- Not secure when system may MAC messages of different lengths (*more in section!*).
- NIST recommends a derivative called CMAC [FYI only]

Another Tool: Hash Functions

You Just Did This

```
franzi@codered:~/sploits$ md5sum exploit0.c  
3a2e6ce795bce4d06df1ff6835d25cea  exploit0.c  
franzi@codered:~/sploits$ █
```

Hash Functions: Main Idea



- Hash function H is a lossy compression function
 - Collision: $h(x)=h(x')$ for distinct inputs x, x'
- $H(x)$ should look “random”
 - Every bit (almost) equally likely to be 0 or 1
- Cryptographic hash function needs a few properties...

Property 1: One-Way

- Intuition: hash should be hard to invert
 - “Preimage resistance”
 - Let $h(x') = y \in \{0,1\}^n$ for a random x'
 - Given y , it should be hard to find any x such that $h(x)=y$
- How hard?
 - Brute-force: try every possible x , see if $h(x)=y$
 - SHA-1 (common hash function) has 160-bit output
 - Expect to try 2^{159} inputs before finding one that hashes to y .

Property 2: Collision Resistance

- Should be hard to find $x \neq x'$ such that $h(x) = h(x')$

Birthday Paradox

- Are there two people in the first 1/8 of this class that have the same birthday?
 - 365 days in a year (366 some years)
 - Pick one person. To find another person with same birthday would take on the order of $365/2 = 182.5$ people
 - **Expect birthday “collision” with a room of only 23 people.**
 - For simplicity, approximate when we expect a collision as $\text{sqrt}(365)$.
- Why is this important for cryptography?
 - 2^{128} different 128-bit values
 - Pick one value at random. To exhaustively search for this value requires trying on average 2^{127} values.
 - **Expect “collision” after selecting approximately 2^{64} random values.**
 - **64 bits** of security against collision attacks, not 128 bits.

Property 2: Collision Resistance

- Should be hard to find $x \neq x'$ such that $h(x) = h(x')$
- Birthday paradox means that brute-force collision search is **only $O(2^{n/2})$, not $O(2^n)$**
 - For SHA-1, this means $O(2^{80})$ vs. $O(2^{160})$

One-Way vs. Collision Resistance

One-wayness does not imply collision resistance.

Collision resistance does not imply one-wayness.

You can prove this by constructing a function that has one property but not the other. (Details on next slide, FYI only.)

One-Way vs. Collision Resistance (Details here mainly FYI)

- One-wayness does not imply collision resistance
 - Suppose g is one-way
 - Define $h(x)$ as $g(x')$ where x' is x except the last bit
 - h is one-way (to invert h , must invert g)
 - Collisions for h are easy to find: for any x , $h(x_0)=h(x_1)$
- Collision resistance does not imply one-wayness
 - Suppose g is collision-resistant
 - Define $y=h(x)$ to be $0x$ if x is n -bit long, $1g(x)$ otherwise
 - Collisions for h are hard to find: if y starts with 0 , then there are no collisions, if y starts with 1 , then must find collisions in g
 - h is not one way: half of all y 's (those whose first bit is 0) are easy to invert (how?); random y is invertible with probab. $\frac{1}{2}$

Property 3: Weak Collision Resistance

- Given randomly chosen x , hard to find x' such that $h(x)=h(x')$
 - Attacker must find collision for a specific x . By contrast, to break collision resistance it is enough to find any collision.
 - Brute-force attack requires $O(2^n)$ time
- Weak collision resistance does not imply collision resistance.

Hashing vs. Encryption

- Hashing is one-way. There is no “un-hashing”
 - A ciphertext can be decrypted with a decryption key... hashes have no equivalent of “decryption”
- Hash(x) looks “random” but can be compared for equality with Hash(x’)
 - Hash the same input twice → same hash value
 - Encrypt the same input twice → different ciphertexts
- Cryptographic hashes are also known as “cryptographic checksums” or “message digests”

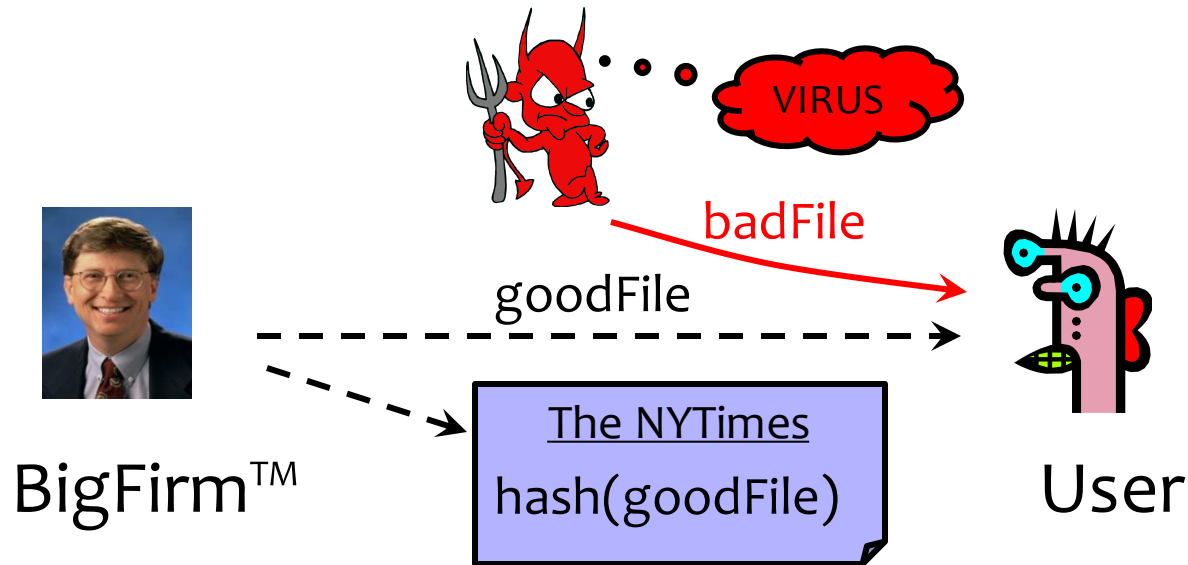
Application: Password Hashing

- Instead of user password, store `hash(password)`
- When user enters a password, compute its hash and compare with the entry in the password file
- Why is hashing better than encryption here?
- System does not store actual passwords!
- Don't need to worry about where to store the key!
- Cannot go from hash to password!

Application: Password Hashing

- Which property do we need?
 - One-wayness?
 - (At least weak) Collision resistance?
 - Both?

Application: Software Integrity



Goal: Software manufacturer wants to ensure file is received by users without modification.

Idea: given goodFile and $\text{hash}(\text{goodFile})$, very hard to find badFile such that $\text{hash}(\text{goodFile}) = \text{hash}(\text{badFile})$

Application: Software Integrity

- Which property do we need?
 - One-wayness?
 - (At least weak) Collision resistance?
 - Both?

Which Property Do We Need?

One-wayness, Collision Resistance, Weak CR?

- UNIX passwords stored as hash(password)
 - **One-wayness:** hard to recover the/a valid password
- Integrity of software distribution
 - **Weak collision resistance**
 - But software images are not really random... may need **full collision resistance** if considering malicious developers

Which Property Do We Need?

- UNIX passwords stored as $\text{hash}(\text{password})$
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 - But software images are not really random... may need **full collision resistance** if considering malicious developers
- Private auction bidding
 - Alice wants to bid B , sends $H(B)$, later reveals B
 - **One-wayness:** rival bidders should not recover B (this may mean that she needs to hash some randomness with B too)
 - **Collision resistance:** Alice should not be able to change her mind to bid B' such that $H(B)=H(B')$