CSE 484 / CSE M 584: Finish Hash Functions + Start Asymmetric Cryptography

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Announcements

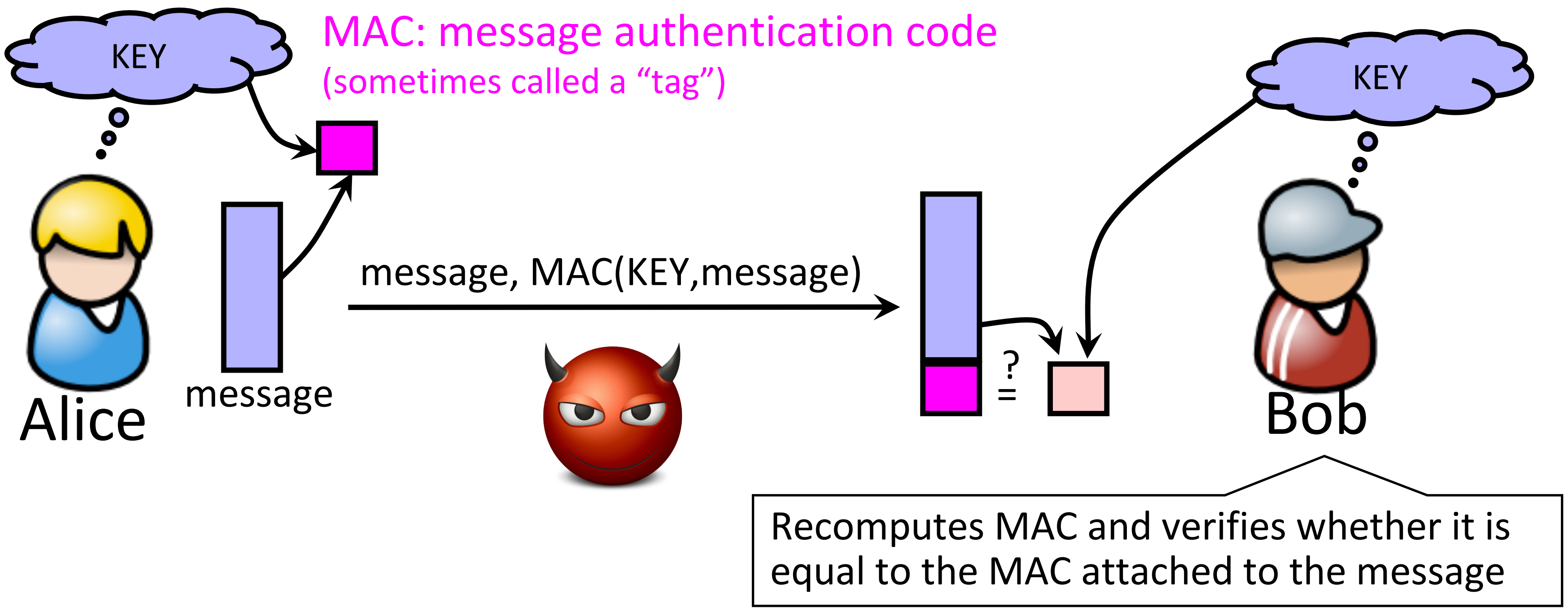
- Things due
  - Lab 1: Thursday
  - Homework 2: Next Friday
    - Individual assignment (no groups)
  - CSE 584M: Don't forget about weekly research readings

Hash Functions Review

- Map large domain to small range (e.g., range of all 160- or 256-bit values)
- Properties:
  - One-Wayness: Given an output (that was computed as the hash of a random domain element), hard to find a preimage
  - Collision Resistance: Hard to find two distinct inputs that map to same output
  - Weak Collision Resistance: Given a point in the domain and its hash in the range, hard to find a new domain element that maps to the same range element

Recall: 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.

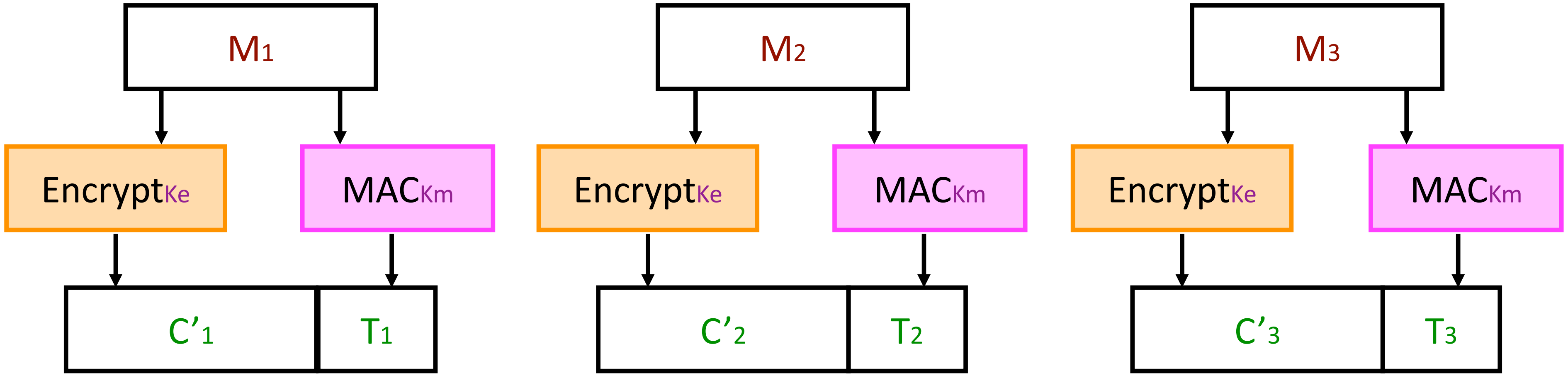
MAC with SHA3

- SHA3(Key || Message)
- Nice and simple ☺
- Previous hash functions couldn't quite be used in this way (see: length extension attack)
  - HMAC construction (FYI)

- Why not encryption? (Historical reasons)
  - Hashing is faster than block ciphers in software
  - Can easily replace one hash function with another
  - There used to be US export restrictions on encryption

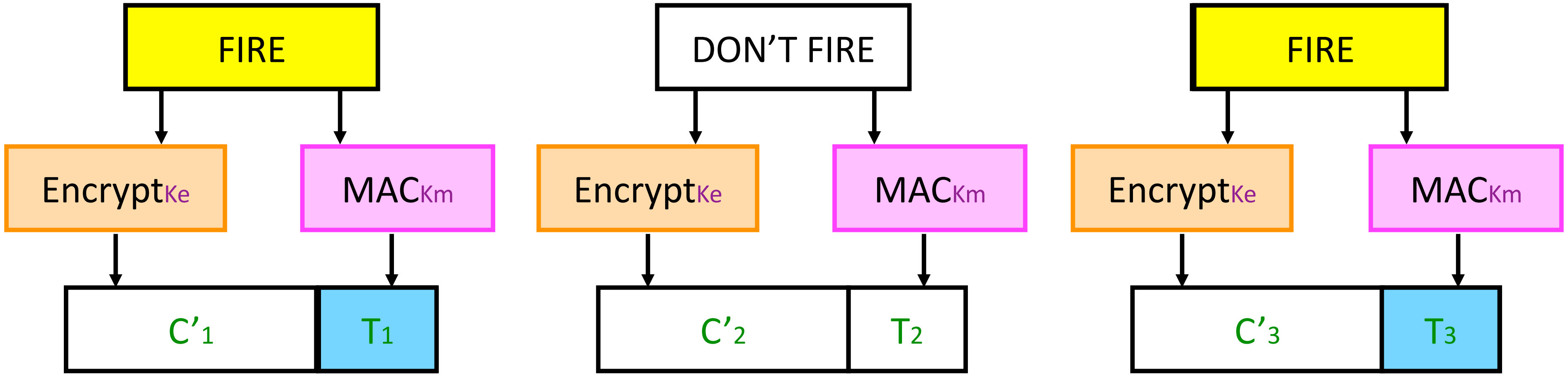
Authenticated Encryption

- What if we want both privacy and integrity?
- Natural approach: combine encryption scheme and a MAC.
- Does this work? → Canvas "quiz" time



Authenticated Encryption

- What if we want both privacy and integrity?
- Natural approach: combine encryption scheme and a MAC.
- But be careful!
  - Obvious approach: Encrypt-and-MAC
  - Problem: MAC is deterministic! same plaintext → same MAC

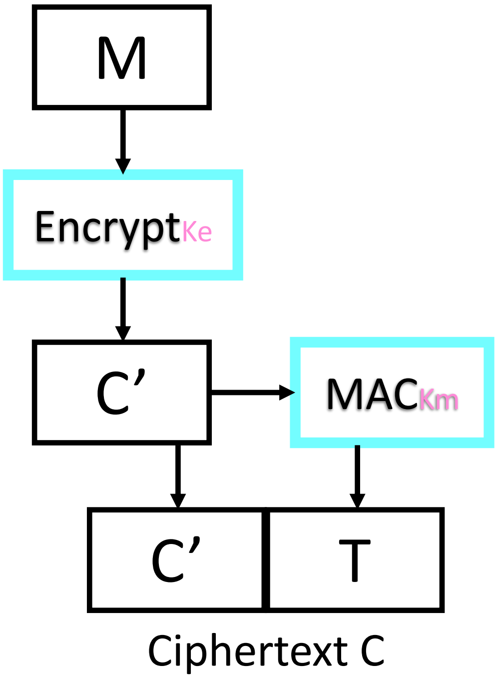


Authenticated Encryption

- Instead:

  Encrypt *then* MAC.

- (Not as good:
  MAC-then-Encrypt)



Encrypt-then-MAC

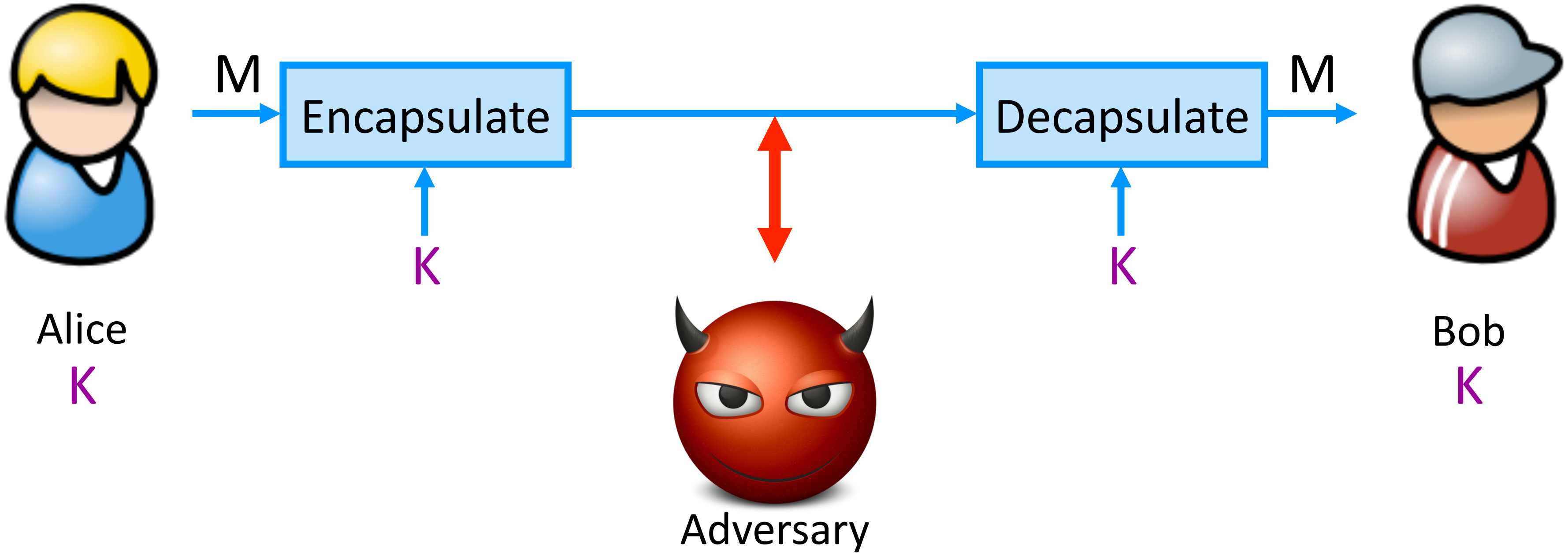
Stepping Back: Flavors of Cryptography

- Symmetric cryptography
  - Both communicating parties have access to a shared random string K, called the key.

- Asymmetric cryptography
  - Each party creates a public key pk and a secret key sk.

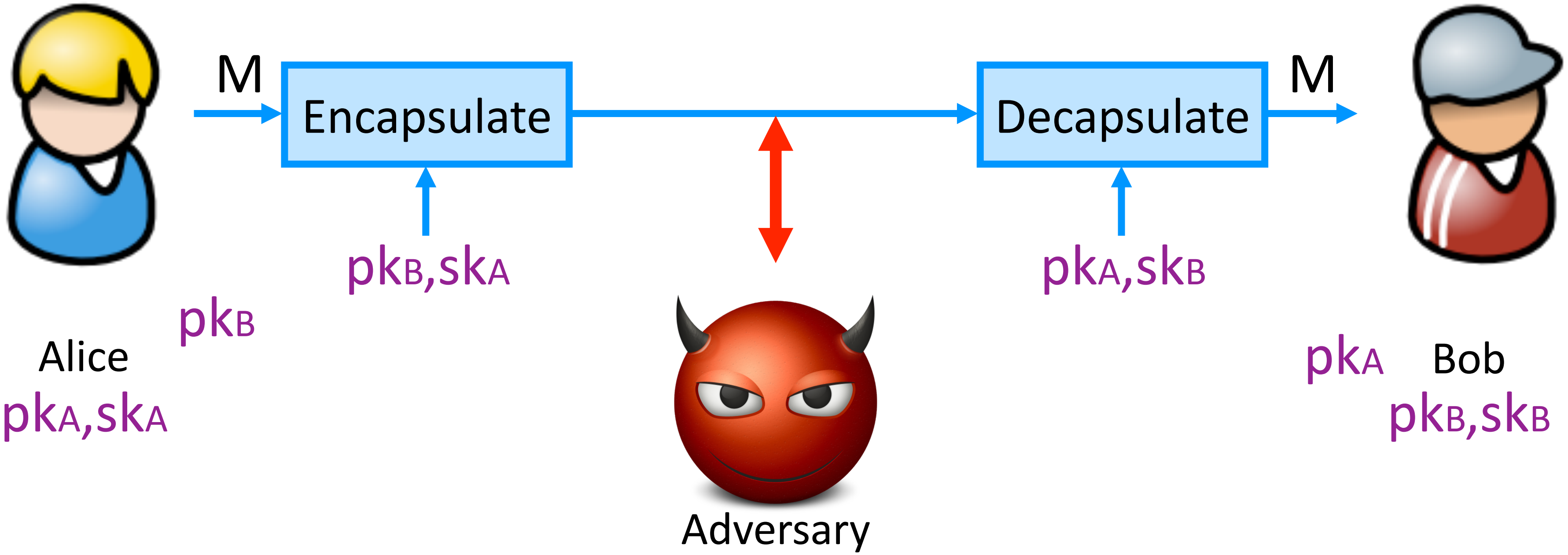
Symmetric Setting

Both communicating parties have access to a shared random string K, called the key.

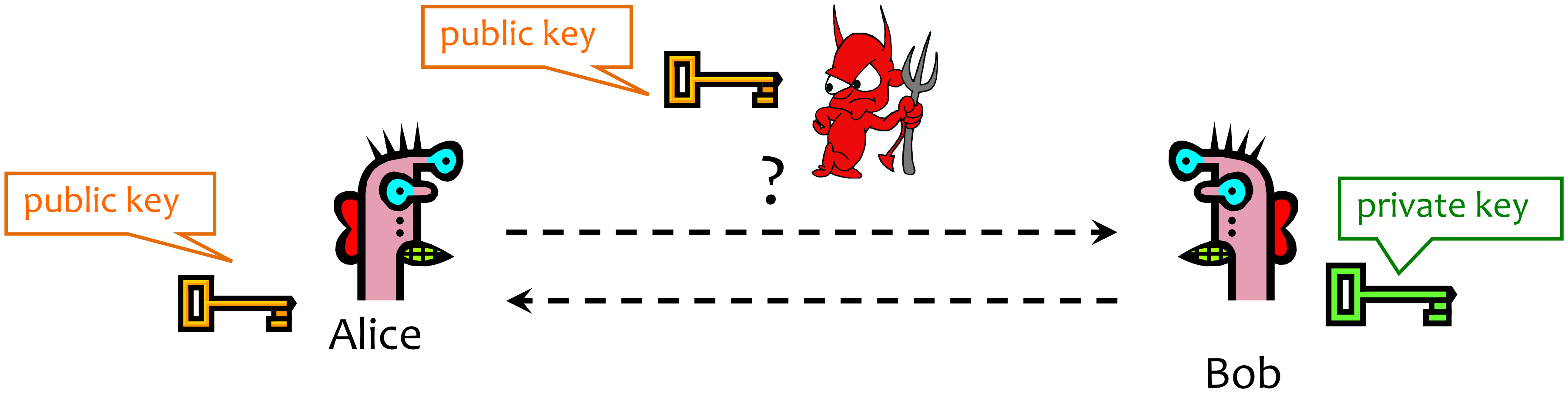


Asymmetric Setting

Each party creates a public key pk and a secret key sk.



Public Key Crypto: Basic Problem



Ignore for now: How do we know it's REALLY Bob's??

Given: Everybody knows Bob's public key
Only Bob knows the corresponding private key

Goals: 1. Alice wants to send a secret message to Bob
2. Bob wants to authenticate themself

Applications of Public Key Crypto

- Encryption for confidentiality
  - Anyone can encrypt a message
    - With symmetric crypto, must know secret key to encrypt
  - Only someone who knows private key can decrypt
  - Key management is simpler (or at least different)
    - Secret is stored only at one site: good for open environments
- Digital signatures for authentication
  - Can "sign" a message with your private key
- Session key establishment
  - Exchange messages to create a secret session key
  - Then switch to symmetric cryptography (why?)

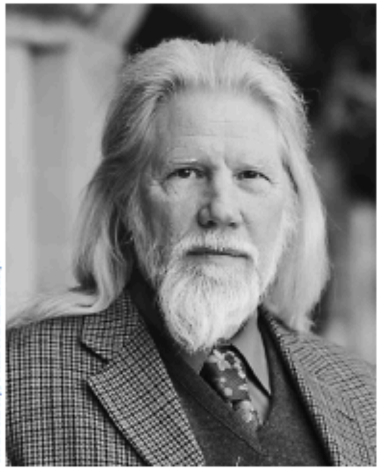
Session Key Establishment

Modular Arithmetic

- Given g and prime p, compute: g^1 mod p, g^2 mod p, … g^{100} mod p
  - For p=11, g=10
    - 10^1 mod 11 = 10, 10^2 mod 11 = 1, 10^3 mod 11 = 10, …
    - Produces cyclic group {10, 1} (order=2)
  - For p=11, g=7
    - 7^1 mod 11 = 7, 7^2 mod 11 = 5, 7^3 mod 11 = 2, …
    - Produces cyclic group {7,5,2,3,10,4,6,9,8,1} (order = 10)
      - Numbers "wrap around" after they reach p
    - g=7 is a "generator" of Z_{11}^*

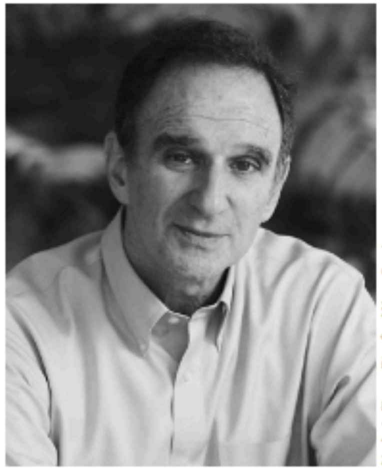
Diffie-Hellman Protocol (1976)

Diffie and Hellman Receive 2015 Turing Award



Rod Searcey/Stanford University.

Whitfield Diffie

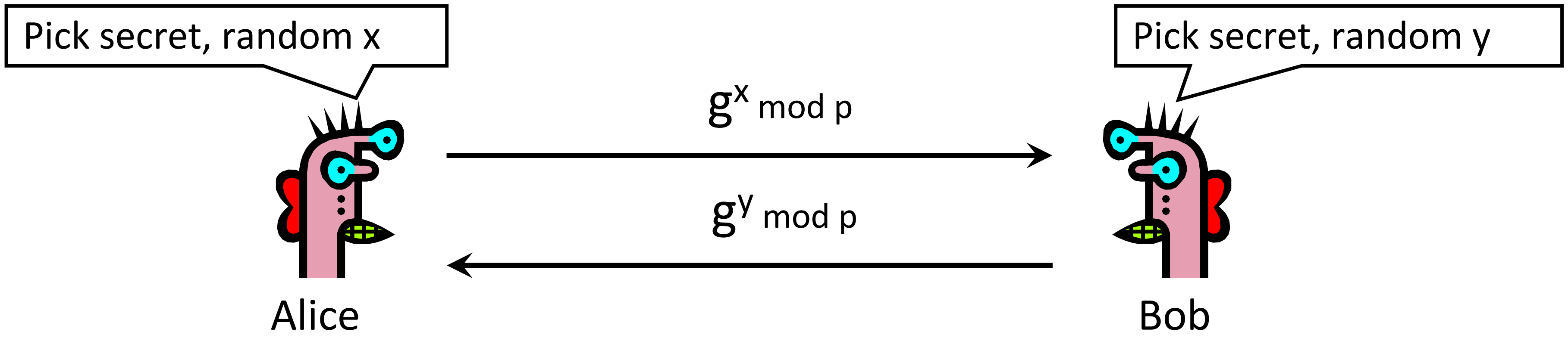


Linda A. Cicero/Stanford News Service.

Martin E. Hellman

Diffie-Hellman Protocol (1976)

- Alice and Bob never met and share no secrets
- <u>Public</u> info: p and g
  - p is a large prime, g is a **generator** of Z_p^*
    - $Z_p^* = \{1, 2 \ldots p\text{-}1\}$; a is in Z_p^* if there is an i such that $a = g^i \bmod p$



Compute $k=(g^y)^x=g^{xy} \bmod p$

Compute $k=(g^x)^y=g^{xy} \bmod p$

Example Diffie Hellman Computation

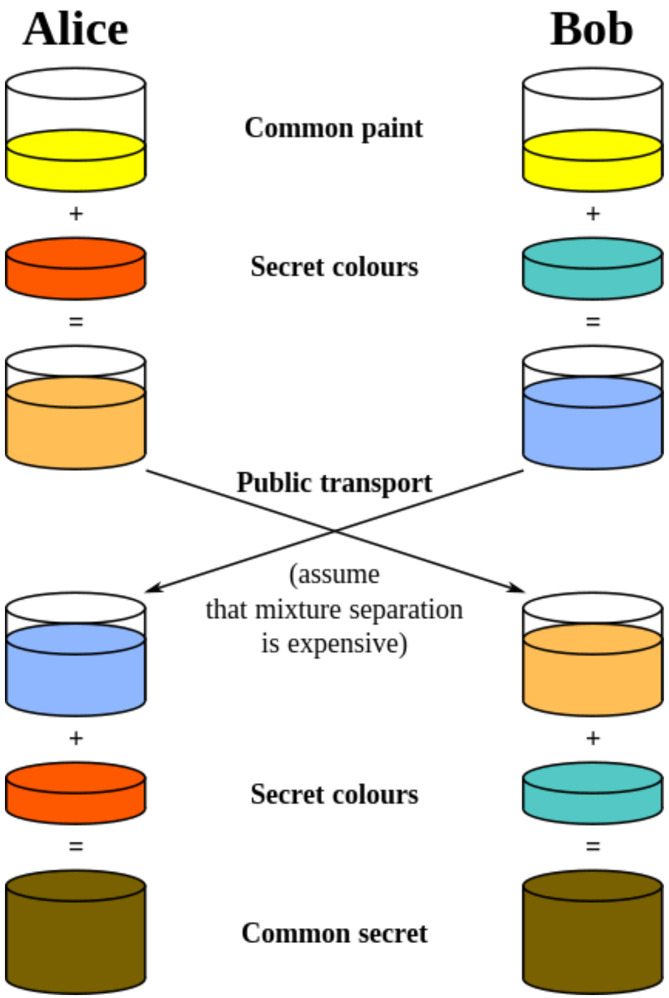
- PUBLIC
  - p = 11
  - g = 2
  - (g is a generator for group mod p)

- Alice: x=9, sends 6 (g^x mod p = 2^9 mod 11 = 6)
- Bob: y=4, send 5 (g^y mod p = 2^4 mod 11 = 5)

- A compute: 5^x mod 11 (5^9 mod 11 = 9)
- B compute 6^y mod 11 (6^4 mod 11 = 9)
- Both get 9

- All computations modulo 11

Diffie-Hellman: Conceptually



Common paint: p and g

Secret colors: x and y

Send over public transport:
$g^x \bmod p$
$g^y \bmod p$

Common secret: $g^{xy} \bmod p$

[from Wikipedia]

Why is Diffie-Hellman Secure?

- Discrete Logarithm (DL) problem:
  given g^x *mod p*, it's hard to extract x
  - There is no known efficient algorithm for doing this
  - This is not enough for Diffie-Hellman to be secure!
- Computational Diffie-Hellman (CDH) problem:
  given g^x and g^y, it's hard to compute g^{xy} *mod p*
  - … unless you know x or y, in which case it's easy
- Decisional Diffie-Hellman (DDH) problem:
  given g^x and g^y, it's hard to tell the difference between
  g^{xy} *mod p* and g^r *mod p* where r is random

Diffie-Hellman Caveats (1)

- Assuming DDH problem is hard (depends on choice of parameters!), Diffie-Hellman protocol is a secure key establishment protocol against passive attackers
  - Common recommendation:
    - Choose p=2q+1, where q is also a large prime
    - Choose g that generates a subgroup of order q in Z_p*
    - DDH is hard in this group
  - Eavesdropper can't tell the difference between the established key and a random value
  - In practice, often hash $g^{xy} \bmod p$, and use the hash as the key
  - Can use the new key for symmetric cryptography

Diffie-Hellman Caveats (2)

- Diffie-Hellman protocol (by itself) does not provide authentication (against <u>active</u> attackers)
  – Person in the middle attack (aka “man in the middle attack”)

Diffie-Hellman Key Exchange Today

- Important Note:
  - We have discussed discrete logs modulo integers
  - Significant advantages in using **elliptic curve groups**
    - Groups with some similar mathematical properties (i.e., are "groups") but have better security and performance (size) properties
    - Today's de-facto standard

Stepping Back: Asymmetric Crypto

- We've just seen session key establishment
  - Can then use shared key for symmetric crypto
- Next: public key encryption
  - For confidentiality
- Then: digital signatures
  - For authenticity