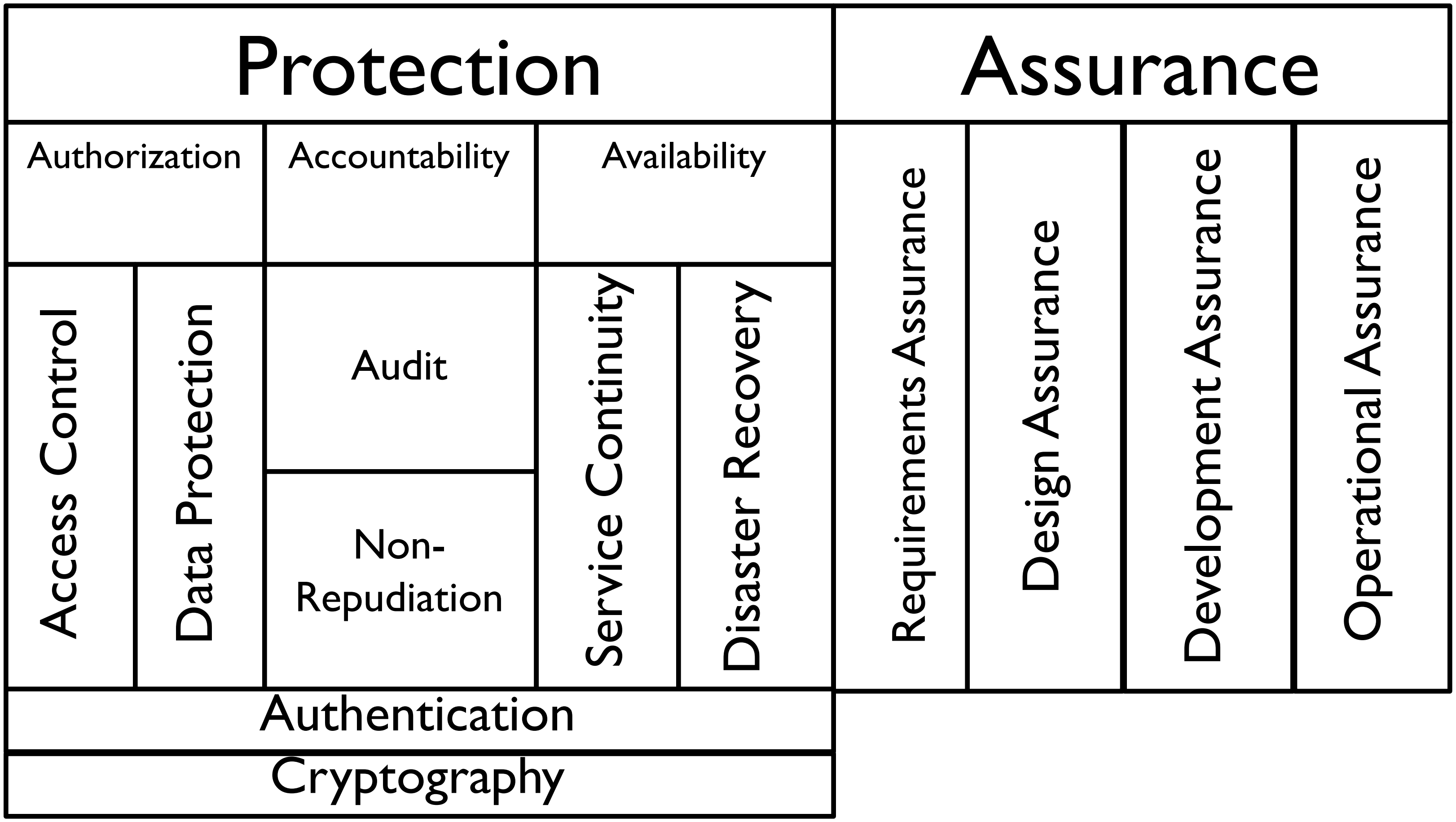
Key Establishment and Authentication Protocols

EECE 412

where we are



Protection

Assurance

Authorization

Accountability

Availability

Access Control

Data Protection

Audit

Non-Repudiation

Service Continuity

Disaster Recovery

Requirements Assurance

Design Assurance

Development Assurance

Operational Assurance

Authentication

Cryptography

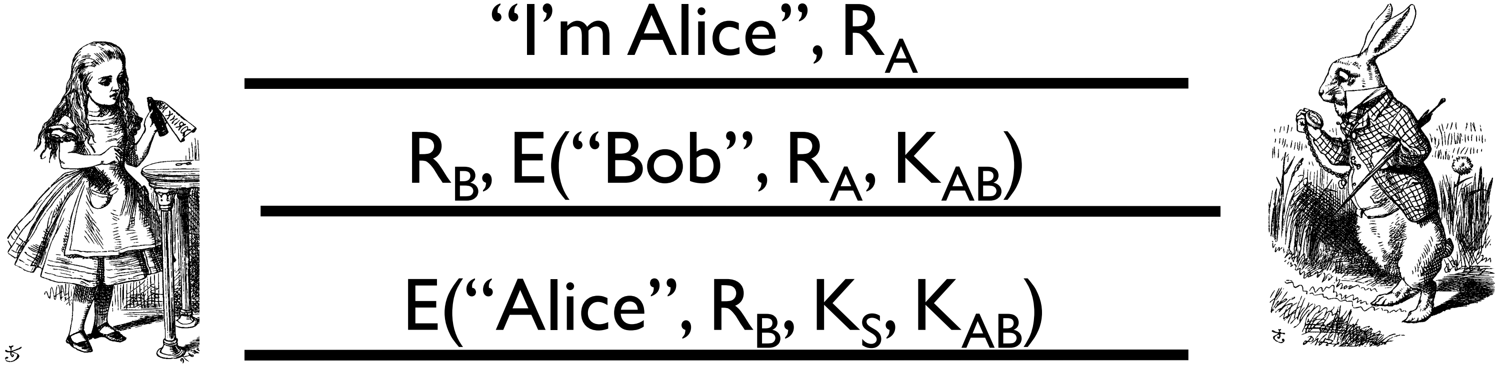
> “The security of a cryptosystem must not depend on keeping secret the crypto-algorithm. The security depends only on keeping secret the key”

Auguste Kerckhoff von Nieuwenhof

Dutch linguist

1883

session key with mutual authentication using symmetric key



"I'm Alice", R_A

R_B, E("Bob", R_A, K_{AB})

E("Alice", R_B, K_S, K_{AB})

Alice

Bob

FPS session key with mutual authentication using symmetric key

Alice

“I’m Alice”, R_A

R_B, E(“Bob”, R_A, $g^b \bmod p$, K_{AB})

E(“Alice”, R_B, $g^a \bmod p$, K_{AB})

Bob

Outline

1. Diffie-Hellman key exchange
2. mutual authentication in networks
3. perfect forward secrecy

learning objectives

You should be able to

- analyze key establishment and authentication protocols and identify their vulnerabilities
- improve or design new key establishment and authentication protocols

Notation

- $X \rightarrow Y : \{ Z \| W \}_{k_{X,Y}}$ == $E(Z, W, k_{X,Y})$
  - X sends Y the message produced by concatenating Z and W enciphered by key $k_{X,Y}$, which is shared by users X and Y
- $A \rightarrow T : \{ Z \}_{k_A} \| \{ W \}_{k_{A,T}}$
  - A sends T a message consisting of the concatenation of Z enciphered using k_A, A's key, and W enciphered using $k_{A,T}$, the key shared by A and T
- r_1, r_2 nonces ("nonrepeating" random numbers)

TLS example

- CipherSuite TLS_RSA_WITH_AES_256_CBC_SHA = { 0x00, 0x35 };
- CipherSuite TLS_DH_RSA_WITH_AES_256_CBC_SHA = { 0x00, 0x37 };

Diffie-Hellman Key Exchange

important trivia

- Invented by Williamson (GCHQ) and, independently, by D and H (Stanford)
- A “key exchange” algorithm
    - Used to establish a shared symmetric key
- Not for encrypting or signing
- Security rests on difficulty of **discrete log** problem: given g, p, and $g^k \bmod p$ find k

how it works

- Let p be prime, let g be a **generator**
  - For any $x \in \{1,2,\ldots,p-1\}$ there is n s.t. $x = g^n \bmod p$

1. Alice selects secret value a
2. Bob selects secret value b
3. Alice sends $g^a \bmod p$ to Bob
4. Bob sends $g^b \bmod p$ to Alice
5. Both compute shared secret $g^{ab} \bmod p$

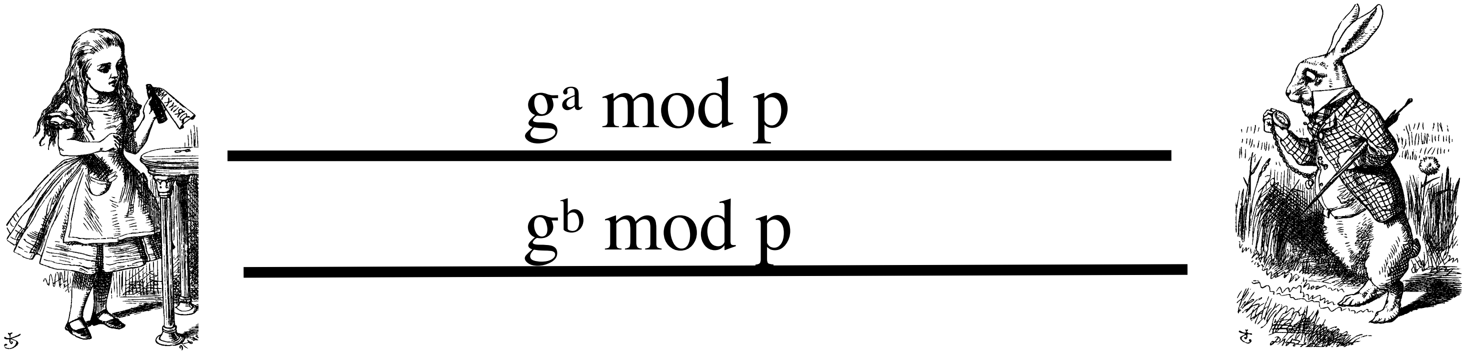
- e.g., Bob computes $(g^a)^b \bmod p = g^{ab} \bmod p$

why it’s hard to attack

- Suppose that Bob and Alice use $g^{ab} \bmod p$ as a symmetric key
- Trudy can see $g^a \bmod p$ and $g^b \bmod p$
- Note $g^a g^b \bmod p = g^{a+b} \bmod p \neq g^{ab} \bmod p$
- If Trudy can find a or b, system is broken
- If Trudy can solve **discrete log** problem, then she can find a or b

the protocol

- **Public:** g and p
- **Secret:** Alice's exponent a, Bob's exponent b



$g^a \bmod p$

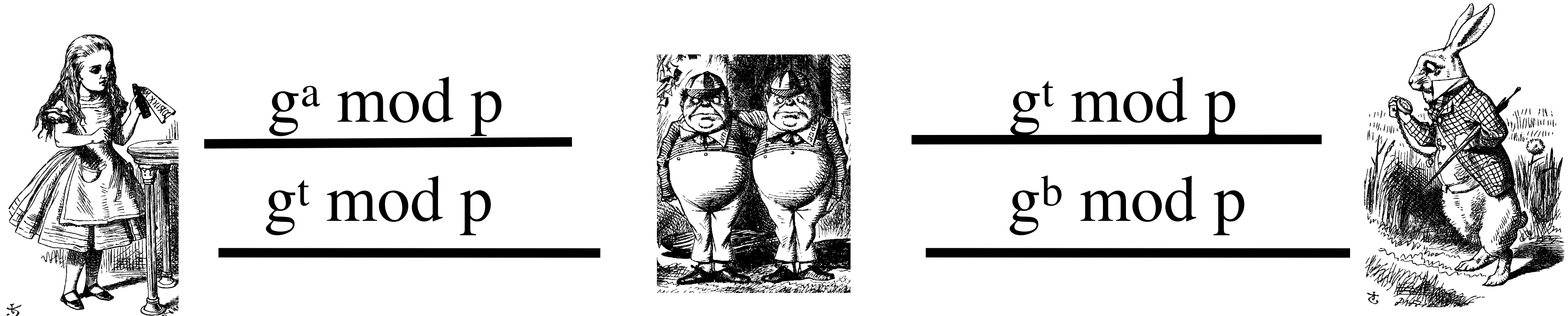
$g^b \bmod p$

Alice, a

Bob, b

- Alice computes $(g^b)^a = g^{ba} = g^{ab} \bmod p$
- Bob computes $(g^a)^b = g^{ab} \bmod p$
- Could use $K = g^{ab} \bmod p$ as symmetric key

Man-in-the-Middle Attack



g^a mod p

g^t mod p

g^t mod p

g^b mod p

Alice, a

Trudy, t

Bob, b

- Trudy shares secret g^{at} mod p with Alice
- Trudy shares secret g^{bt} mod p with Bob
- Alice and Bob don’t know Trudy exists!

how to prevent MiM attack?

- Encrypt DH exchange with symmetric key
- Encrypt DH exchange with public key
- Sign DH values with private key
- Other?

You **MUST** be aware of MiM attack on Diffie-Hellman

Authentication Protocols

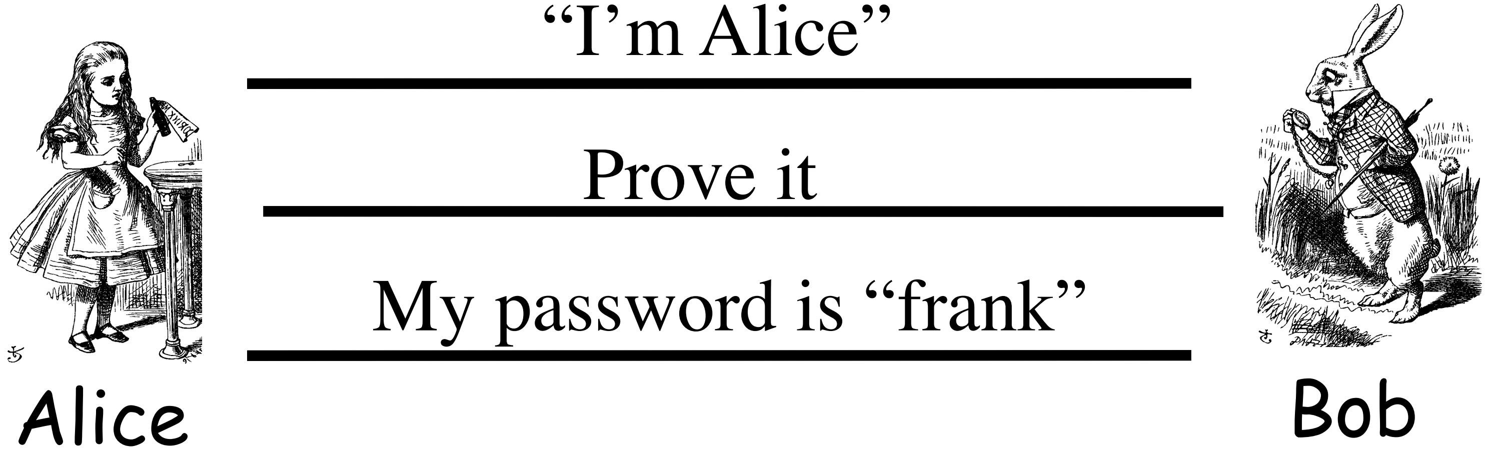
basics

- Alice must prove her identity to Bob
  - Alice and Bob can be humans or computers
- May also require Bob to prove he's Bob (mutual authentication)
- May also need to establish a session key
- May have other requirements, such as
  - Use only public keys
  - Use only symmetric keys
  - Use only a hash function
  - Anonymity, plausible deniability, etc., etc.

why authentication can be hard?

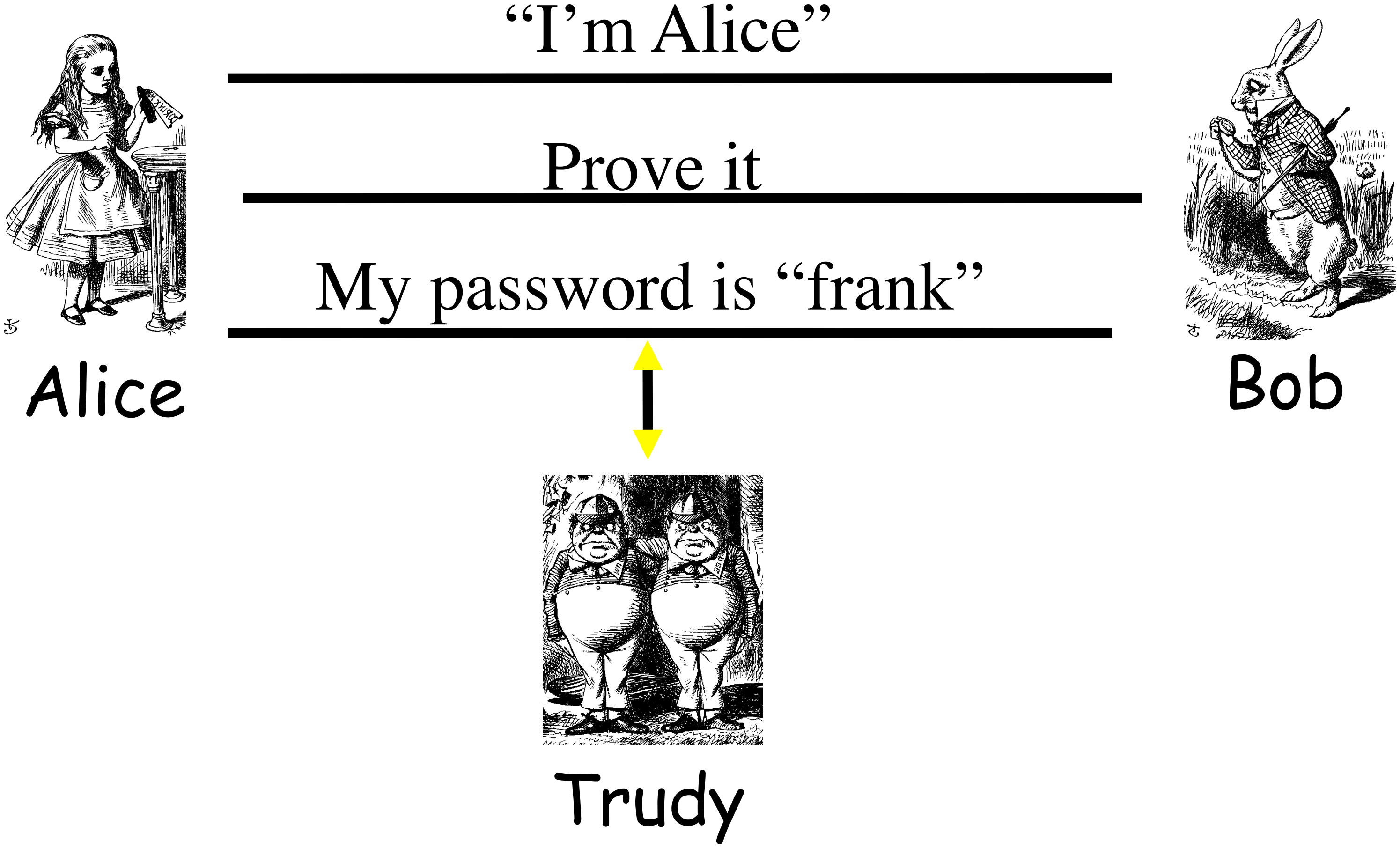
- relatively simple on a stand-alone computer
  - "Secure path" is the primary issue
  - main concern is an attack on authentication software
- much more complex over a network
  - attacker can passively observe messages
  - attacker can replay messages
  - active attacks may be possible (insert, delete, change messages)

simple authentication



- Simple and may be OK for standalone system
- But insecure for networked system
  - Subject to a replay attack (next 2 slides)
  - Bob must know Alice’s password

authentication attack



“I’m Alice”

Prove it

My password is “frank”

Alice

Bob

Trudy

authentication Attack

Trudy

“I’m Alice”

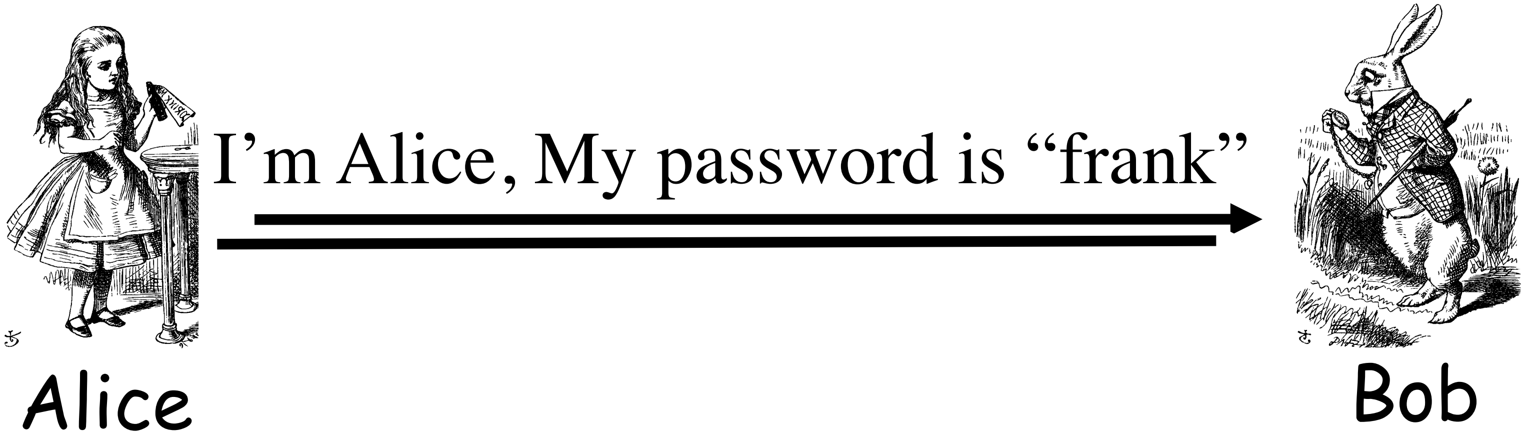
Prove it

My password is “frank”

Bob

- This is a **replay** attack
- How can we prevent a replay?

Simple Authentication



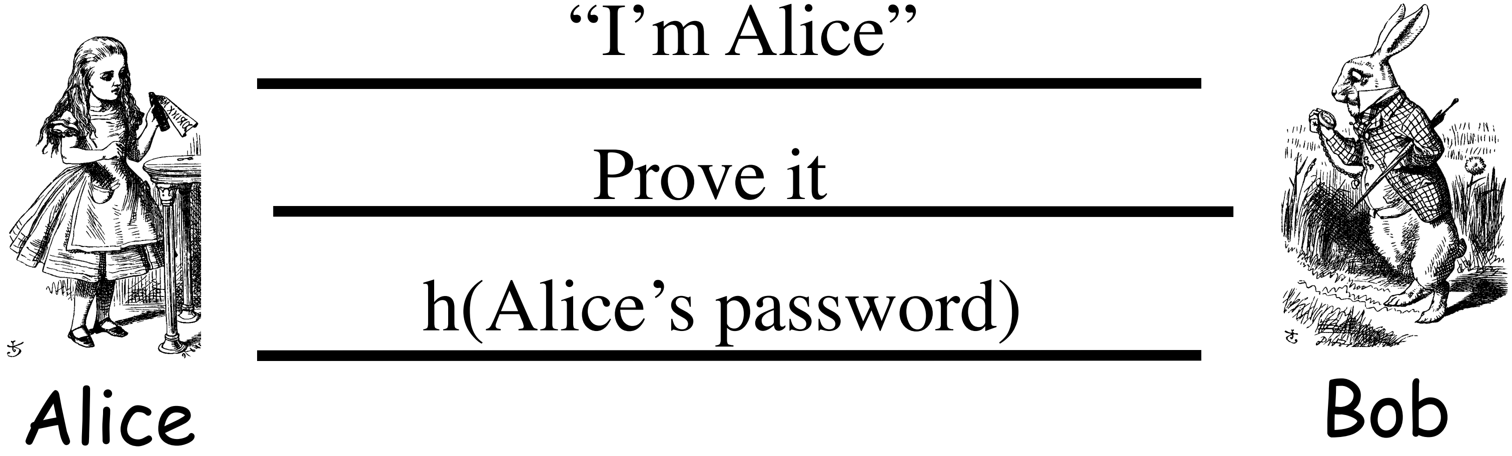
I’m Alice, My password is “frank”

Alice

Bob

- More efficient…
- But same problem as previous version

Better Authentication



- Better since it hides Alice’s password
  - From both Bob and attackers
- But still subject to replay

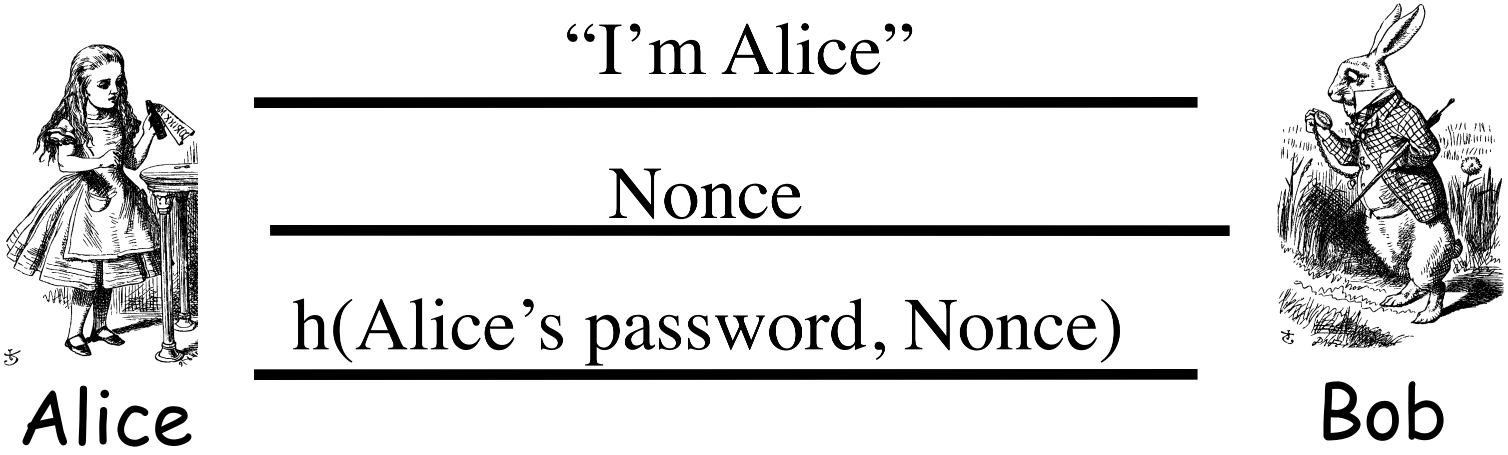
challenge-response

- To prevent replay, challenge-response used
- Suppose Bob wants to authenticate Alice
    - Challenge sent from Bob to Alice
    - Only Alice can provide the correct response
    - Challenge chosen so that replay is not possible
- How to accomplish this?
    - Password is something only Alice should know…
    - For freshness, a "number used once" or **nonce**

illustration

Monty Python and the Holy Grail (1h18m)

simple challenge-response



“I’m Alice”

Nonce

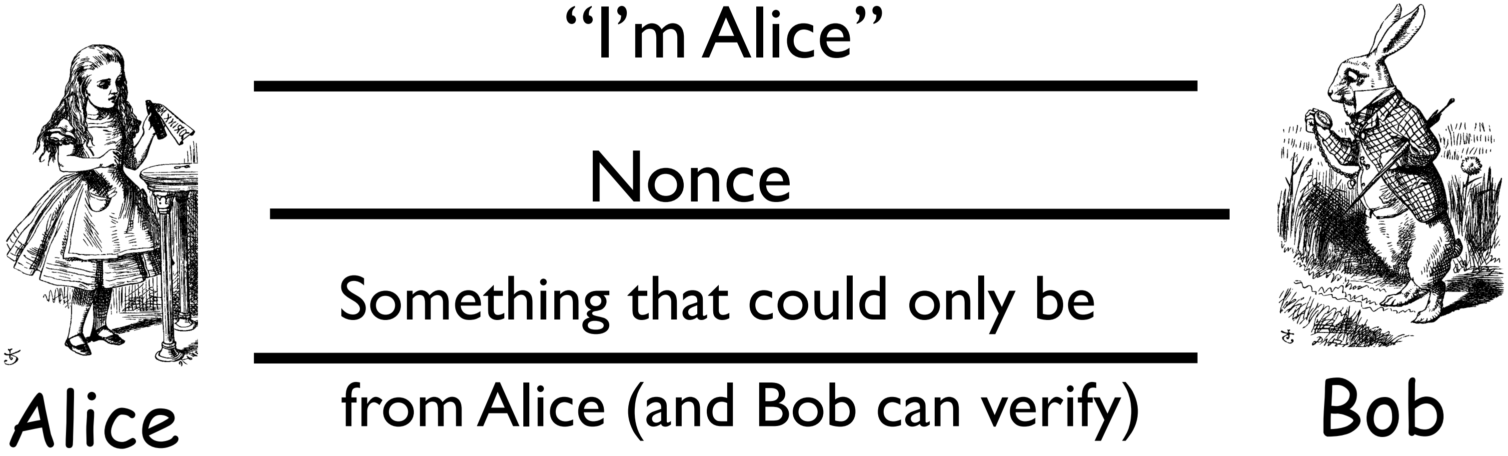
h(Alice’s password, Nonce)

Alice

Bob

- Nonce is the **challenge**
- The hash is the **response**
- Nonce prevents replay, insures freshness
- Password is something Alice knows
- Note that Bob must know Alice’s password

general challenge-response



“I’m Alice”

Nonce

Something that could only be from Alice (and Bob can verify)

- What can we use to achieve this?
- Hashed pwd works, crypto might be better

symmetric key notation

- Encrypt plaintext P with key K

  C = E(P,K)

- Decrypt ciphertext C with key K

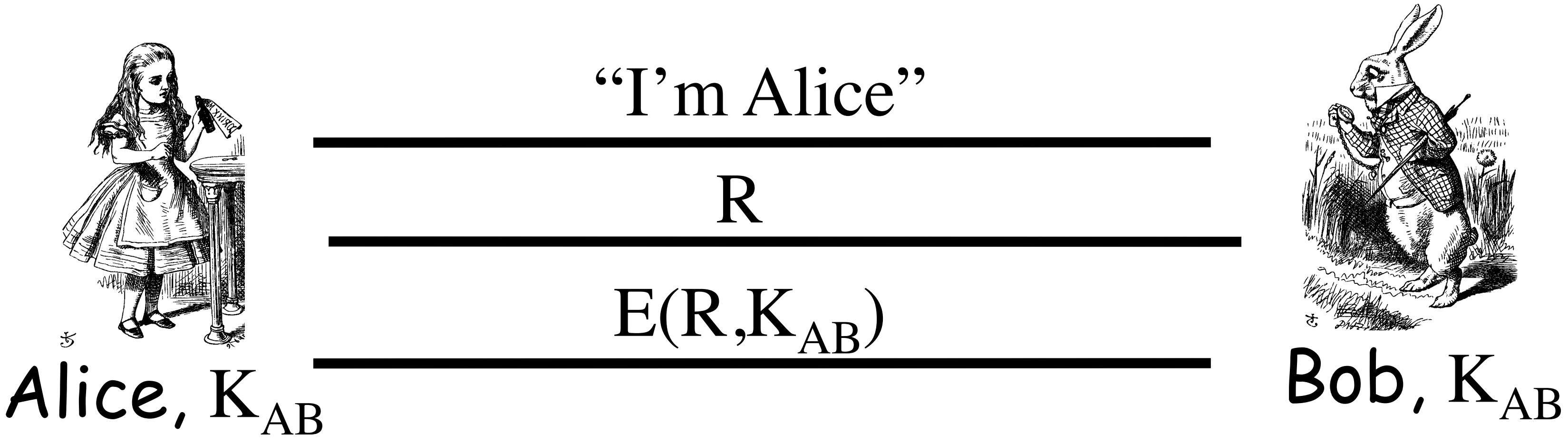
  P = D(C,K)

- Here, we are concerned with attacks on **protocols**, not directly on the crypto
- We assume that crypto algorithm is secure

authentication with symmetric key

- Alice and Bob share symmetric key K_{AB}
- key K_{AB} known only to Alice and Bob
- authenticate by proving knowledge of shared symmetric key
- how to accomplish this?
  - must not reveal key
  - must not allow replay attack

authentication with symmetric key



“I’m Alice”

R

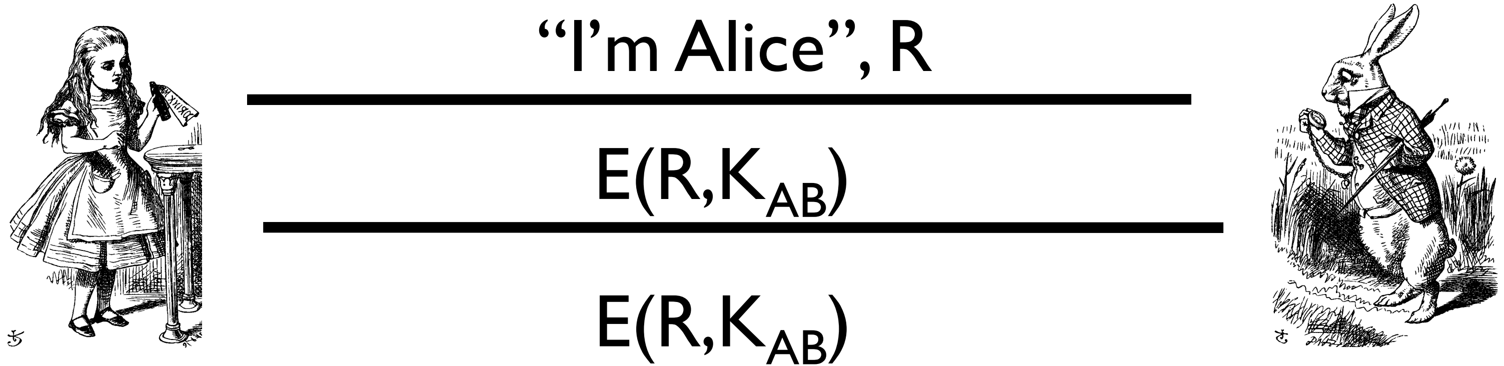
E(R,K_{AB})

Alice, K_{AB}

Bob, K_{AB}

- Secure method for Bob to authenticate Alice
- Alice does not authenticate Bob
- Can we achieve mutual authentication?

mutual authentication?



“I’m Alice”, R

$E(R,K_{AB})$

$E(R,K_{AB})$

Alice

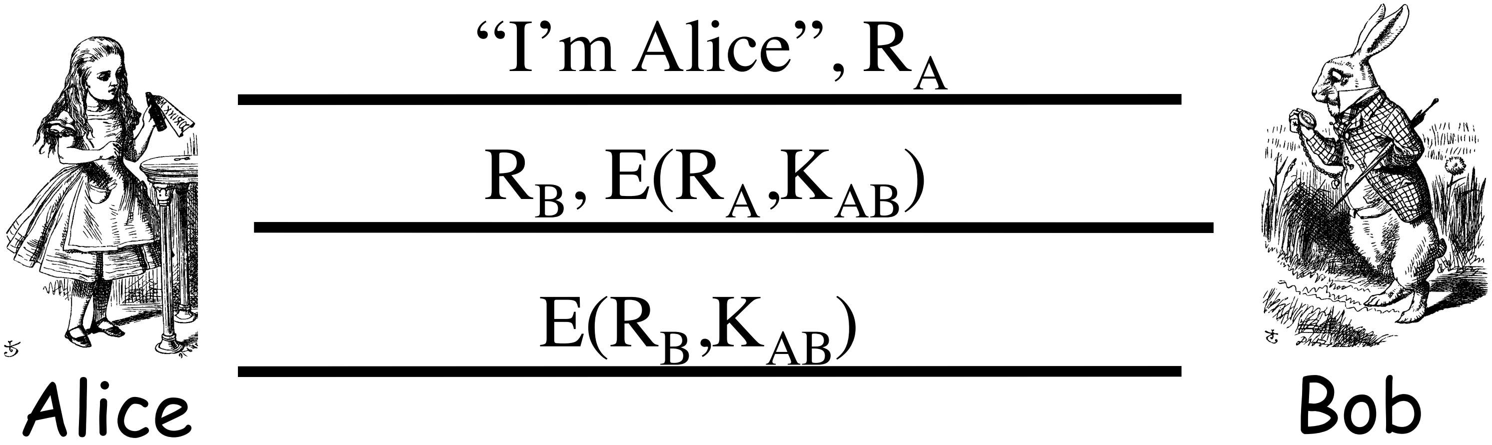
Bob

- What’s wrong with this picture?
- “Alice” could be Trudy (or anybody else)!

Mutual Authentication

- Since we have a secure one-way authentication protocol…
- The obvious thing to do is to use the protocol twice
  - Once for Bob to authenticate Alice
  - Once for Alice to authenticate Bob
- This has to work…

Mutual Authentication



“I’m Alice”, R_A

R_B, $E(R_A,K_{AB})$

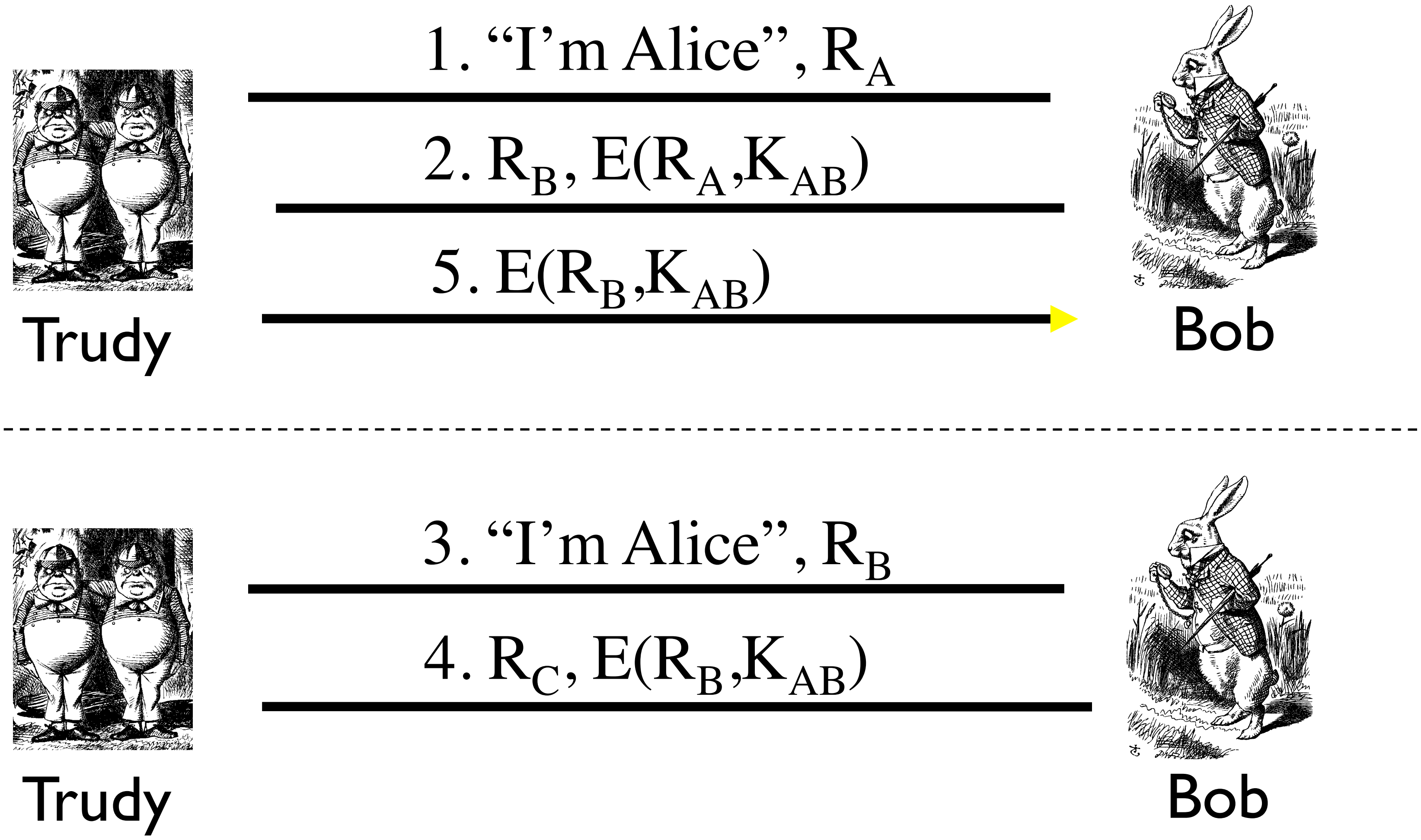
$E(R_B,K_{AB})$

Alice

Bob

- This provides mutual authentication
- Is it secure?

attack on mutual authentication



1. "I'm Alice", R_A

2. R_B, $E(R_A,K_{AB})$

5. $E(R_B,K_{AB})$

3. "I'm Alice", R_B

4. R_C, $E(R_B,K_{AB})$

Notes on Mutual Authentication

- Our one-way authentication protocol **not** secure for mutual authentication
- Protocols are subtle!
- The "obvious" thing may not be secure
- Also, if assumptions or environment changes, protocol may not work
    - This is a common source of security failure
    - For example, Internet protocols

mutual authentication with symmetric key

Alice

“I’m Alice”, R_A

R_B, E(“Bob”, R_A, K_{AB})

E(“Alice”, R_B, K_{AB})

Bob

- Do these “insignificant” changes help?
- Yes!

session key with mutual authentication using symmetric key

Alice

“I’m Alice”, R_A

R_B, E(“Bob”, R_A, K_{AB})

E(“Alice”, R_B, K_S, K_{AB})

Bob

Perfect Forward Secrecy

Perfect Forward Secrecy

- The concern…
  - Alice encrypts message with shared key K_{AB} and sends ciphertext to Bob
  - Trudy records ciphertext and later attacks Alice's (or Bob's) computer to find K_{AB}
  - Then Trudy decrypts recorded messages

Perfect forward secrecy (PFS): Trudy cannot later decrypt recorded ciphertext

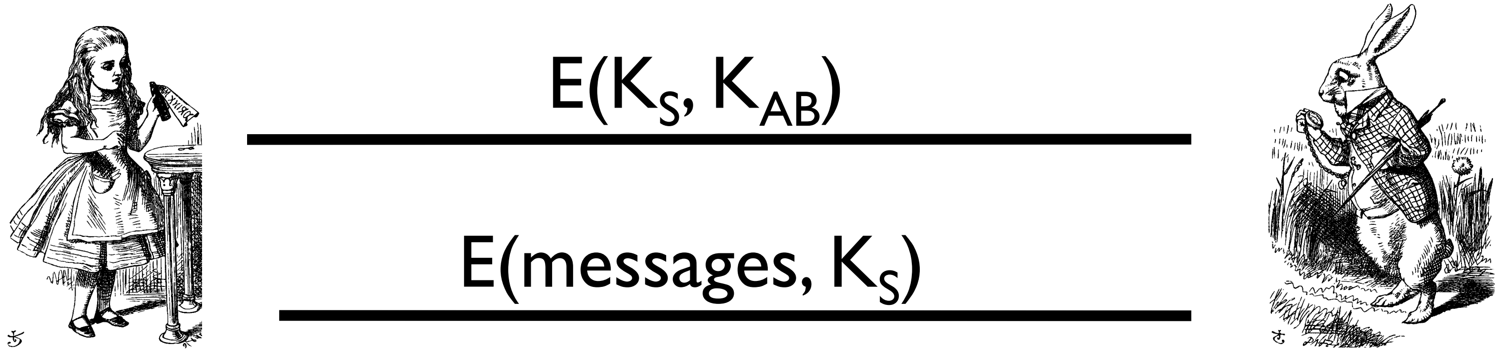
  - Even if Trudy gets key K_{AB} or other secret(s)

- Is PFS possible?

Perfect Forward Secrecy

- For perfect forward secrecy, Alice and Bob cannot use K_{AB} to encrypt
- Instead they must use a **session key** K_S and forget it after it's used
- Problem: How can Alice and Bob agree on session key K_S and insure PFS?

naïve session key protocol



$E(K_S, K_{AB})$

$E(\text{messages}, K_S)$

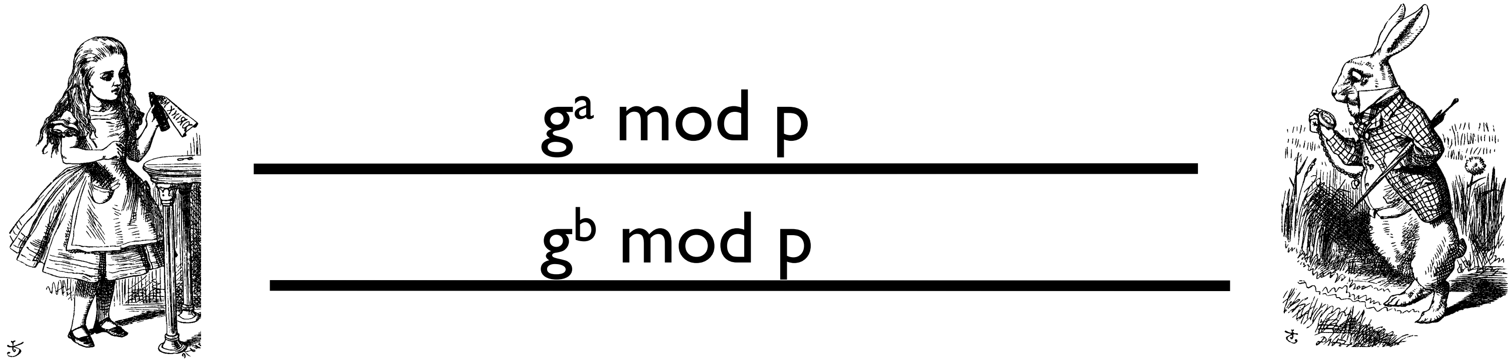
Alice, K_{AB}

Bob, K_{AB}

- Trudy could also record $E(K_S,K_{AB})$
- If Trudy gets K_{AB}, she gets K_S

perfect forward secrecy

- Can use **Diffie-Hellman** for PFS
- Recall Diffie-Hellman: public g and p



$g^a \bmod p$

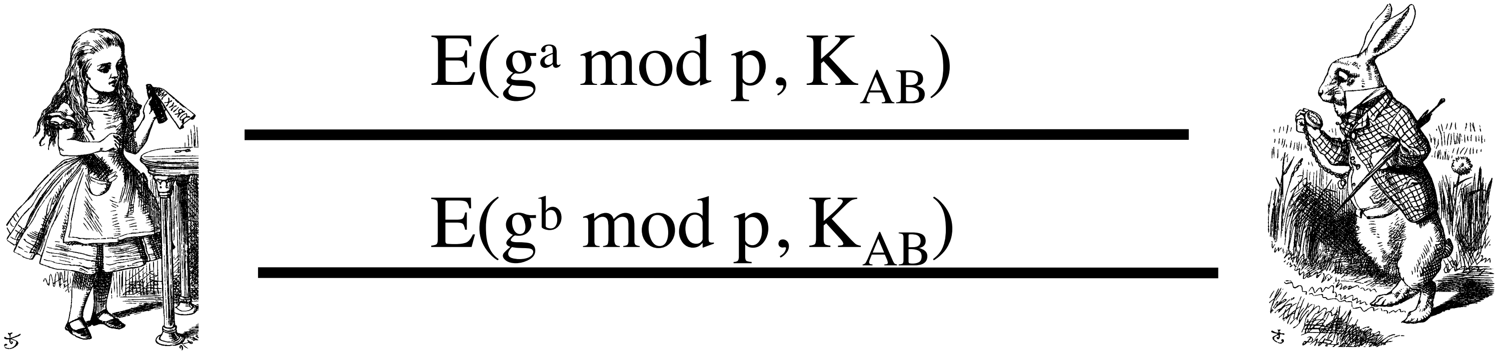
$g^b \bmod p$

Alice, a

Bob, b

- But Diffie-Hellman is subject to MiM
- How to get PFS and prevent MiM?

PFS session key via DH



$E(g^a \bmod p, K_{AB})$

$E(g^b \bmod p, K_{AB})$

Alice, a

Bob, b

- Session key $K_S = g^{ab} \bmod p$
- Alice forgets a, Bob forgets b

Ephemeral Diffie-Hellman

- Not even Alice and Bob can later recover K_S
- Other ways to do PFS?

mutual authentication with symmetric key

Alice

“I’m Alice”, R_A

R_B, E(“Bob”, R_A, K_{AB})

E(“Alice”, R_B, K_{AB})

Bob

- Do these “insignificant” changes help?
- Yes!

FPS session key with mutual authentication using symmetric key

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“I’m Alice”, R_A

R_B, E(“Bob”, R_A, $g^b \bmod p$, K_{AB})

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