Authentication Protocols

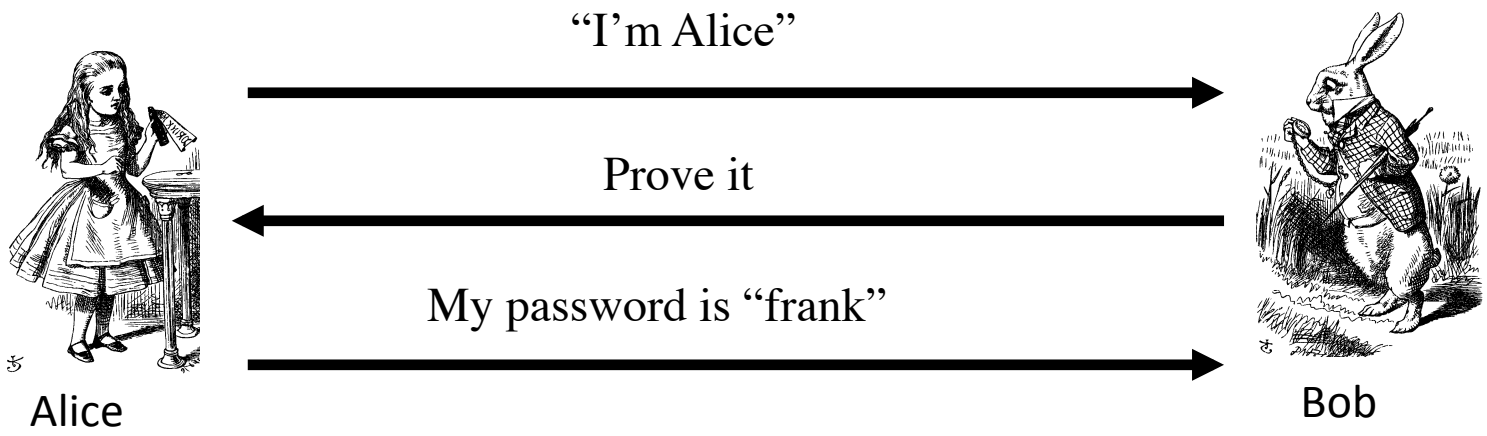
Authentication

- 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)
- Probably need to establish a **session key**
- May have other requirements, such as
  - Use public keys
  - Use symmetric keys
  - Use hash functions
  - Anonymity, plausible deniability, etc., etc.

Authentication

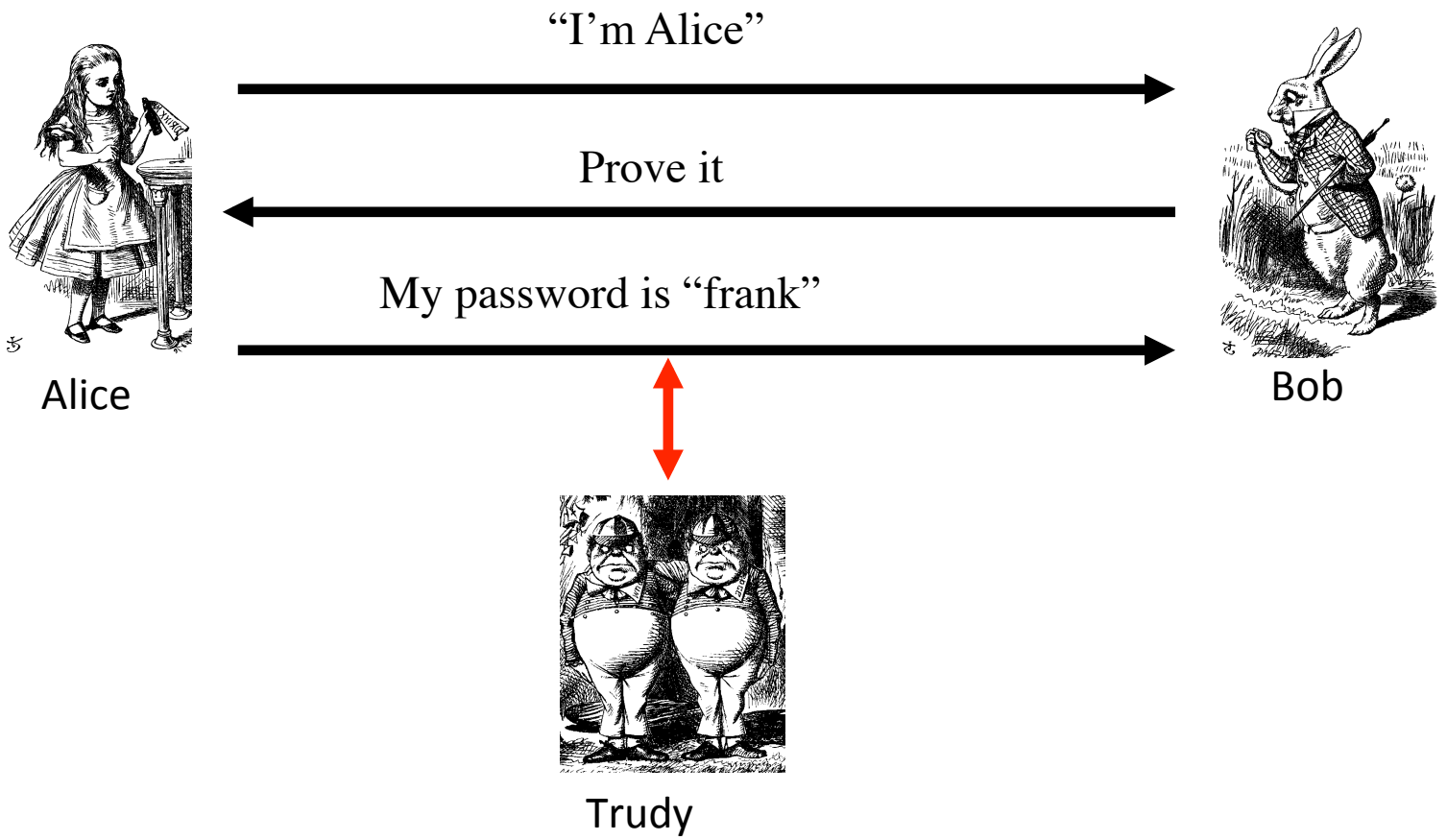
- Authentication on a stand-alone computer is relatively simple
  - Hash password with salt
  - "Secure path," attacks on authentication software, keystroke logging, etc., can be issues
- Authentication over a network is challenging
  - Attacker can passively observe messages
  - Attacker can replay messages
  - Active attacks possible (insert, delete, change)

Simple Authentication

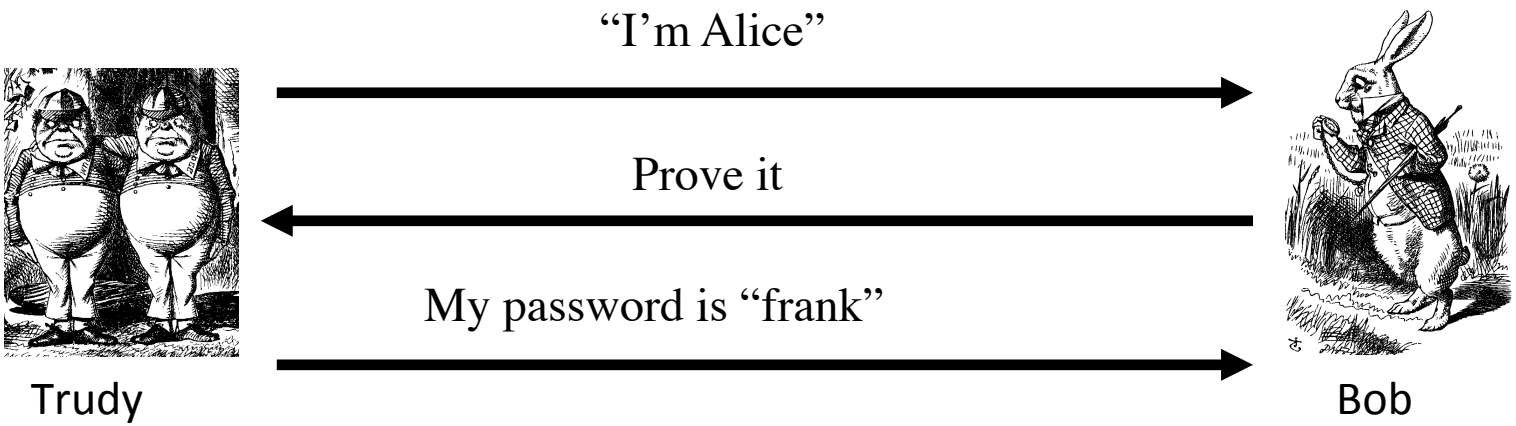


- Simple and may be OK for standalone system
- But insecure for networked system
  - Subject to a **replay** attack (next 2 slides)
  - Also, Bob must know Alice's password

Authentication Attack



Authentication Attack



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

Simple Authentication

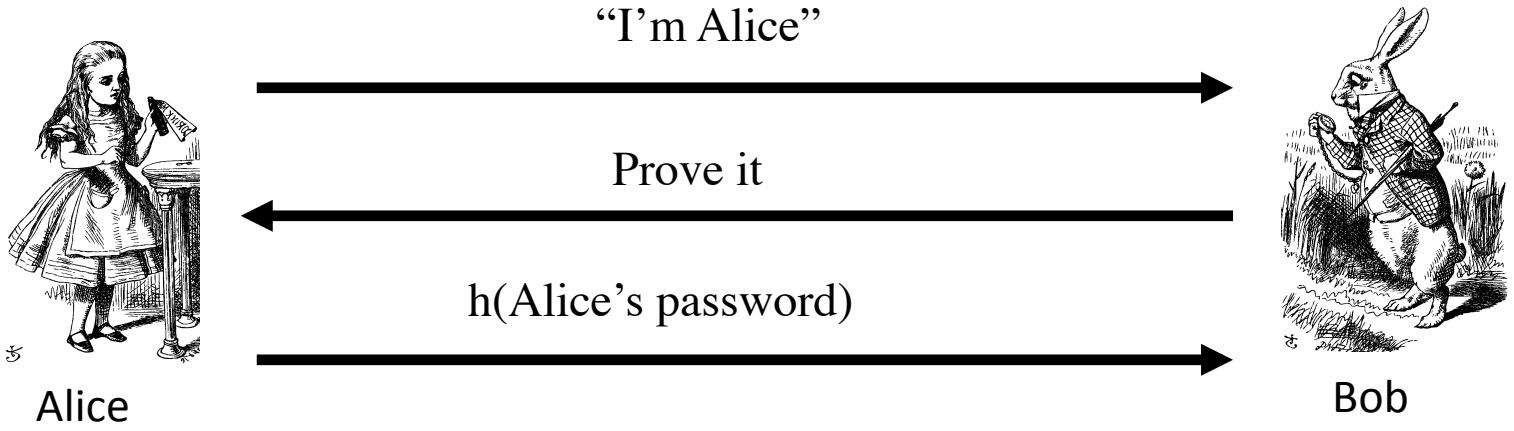
Alice

I'm Alice, my password is "frank"

Bob

- More efficient, but…
- … same problem as previous version

Better Authentication



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

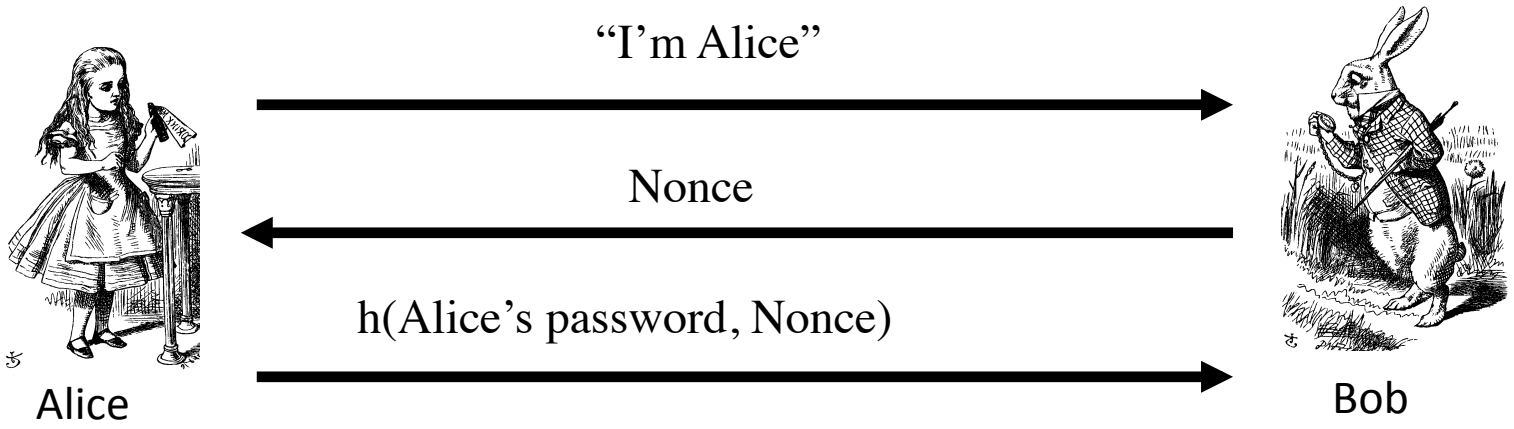
Challenge-Response

- To prevent replay, use ***challenge-response***
  - Goal is to ensure "freshness"
- Suppose Bob wants to authenticate Alice
  - ***Challenge*** sent from Bob to Alice
- Challenge is chosen so that…
  - Replay is not possible
  - Only Alice can provide the correct ***response***
  - Bob can verify the response

Nonce

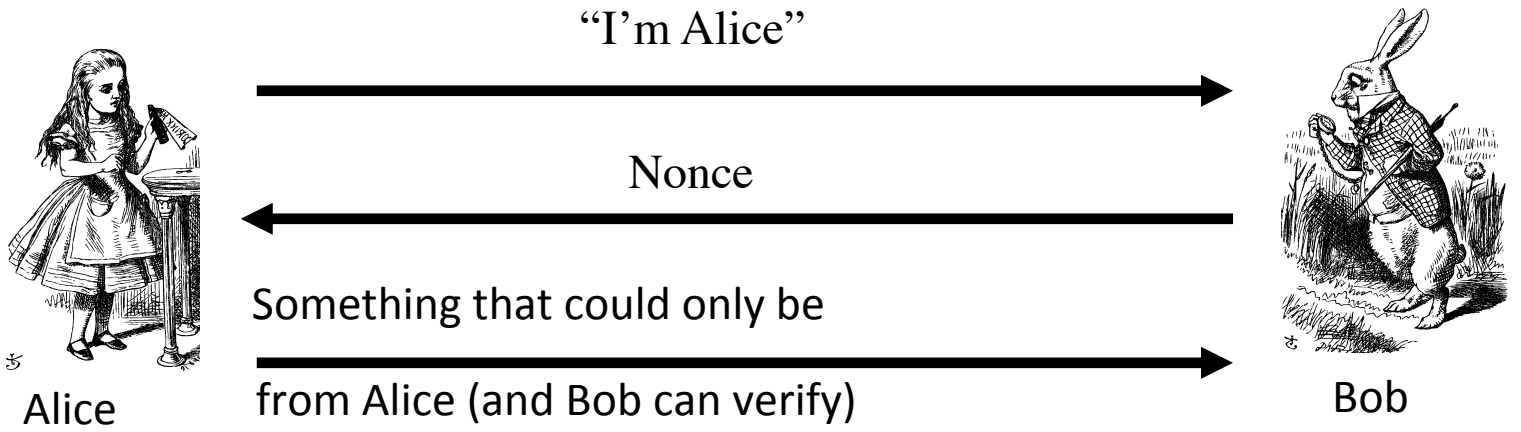
- To ensure freshness, can employ a **nonce**
  - Nonce == **n**umber used **once**
- What to use for nonces?
  - That is, what is the challenge?
- What should Alice do with the nonce?
  - That is, how to compute the response?
- How can Bob verify the response?
- Should we rely on passwords or keys?

Challenge-Response



- Nonce is the challenge
- The hash is the response
- Nonce prevents replay, ensures freshness
- Password is something Alice knows
- Note: Bob must know Alice's pwd to verify

Generic Challenge-Response



- In practice, how to achieve this?
- Hashed password works, but…
- Encryption is better here (Why?)

Symmetric Key Notation

- Encrypt plaintext P with key K

  $$C = E(P,K)$$

- Decrypt ciphertext C with key K

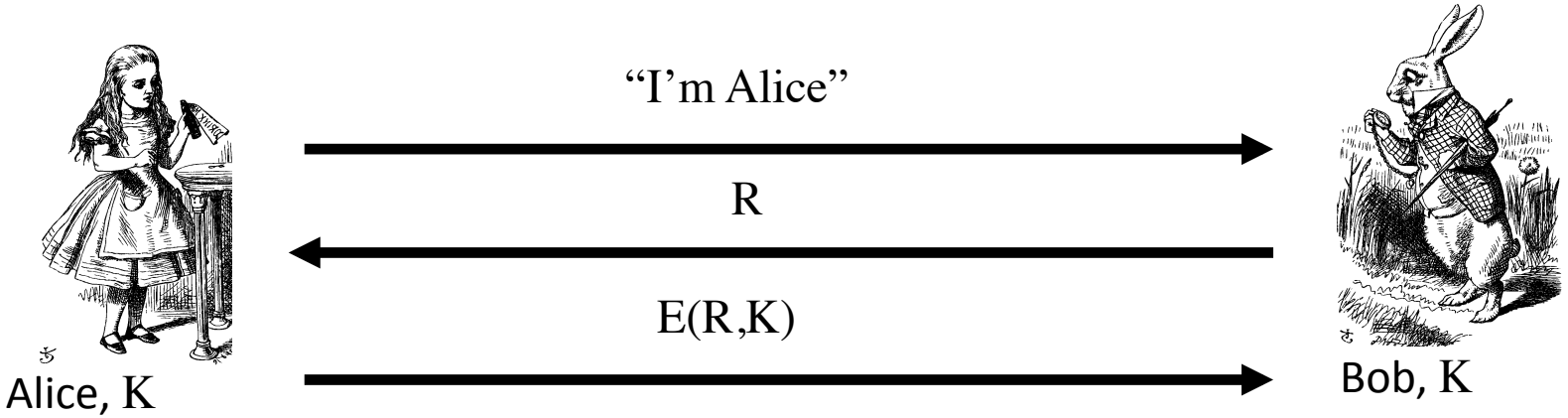
  $$P = D(C,K)$$

- Here, we are concerned with attacks on protocols, **not** attacks on crypto
  - So, we assume crypto algorithms are secure

Authentication: Symmetric Key

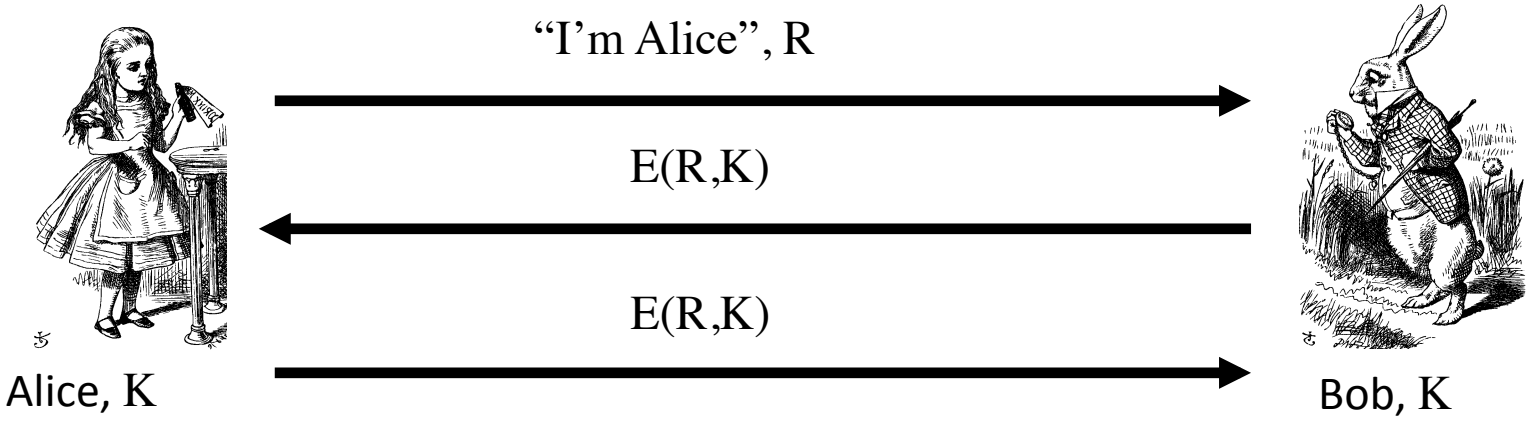
- Alice and Bob share symmetric key K
- Key K known only to Alice and Bob
- Authenticate by proving knowledge of shared symmetric key
- How to accomplish this?
  - Cannot reveal key, must not allow replay (or other) attack, must be verifiable, …

Authentication with Symmetric Key



- Secure method for Bob to authenticate Alice
- Alice does not authenticate Bob
- So, can we achieve mutual authentication?

Mutual Authentication?

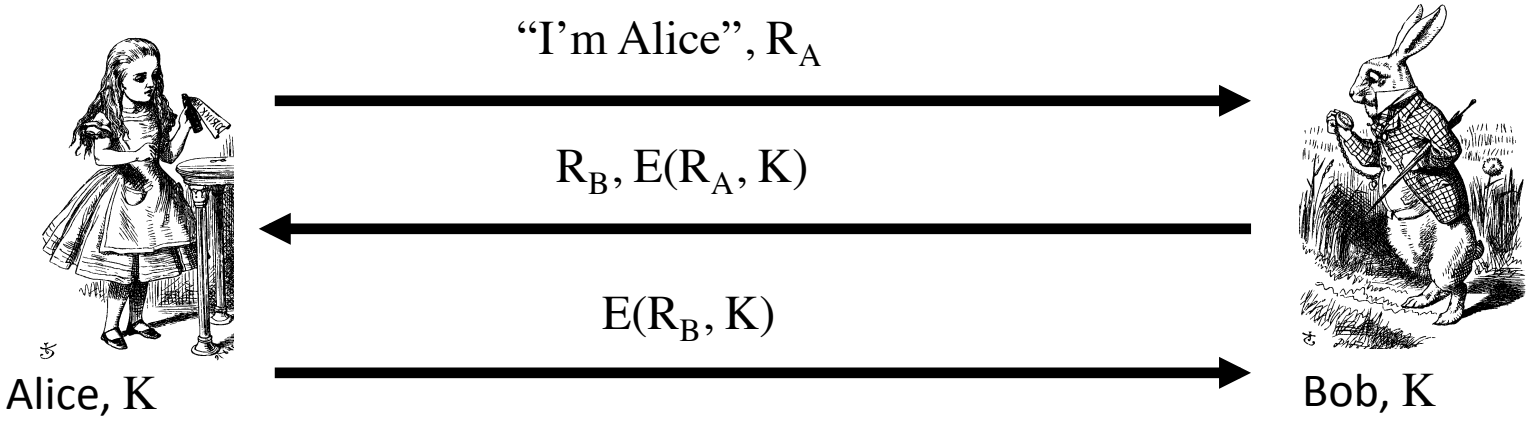


- What's wrong with this picture?
- "Alice" could be Trudy (or anybody else)!

Mutual Authentication

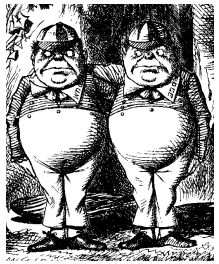
- Since we have a secure one-way authentication protocol…
- The obvious thing to do is to use the protocol twice
  - Once for Bob to authenticate Alice
  - Once for Alice to authenticate Bob
- This has got to work…

Mutual Authentication



- This provides mutual authentication…
- …or does it? See the next slide

Mutual Authentication Attack



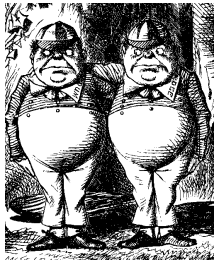
Trudy

1. "I'm Alice", R_A

2. R_B, $E(R_A, K)$

5. $E(R_B, K)$

Bob, K



Trudy

3. "I'm Alice", R_B

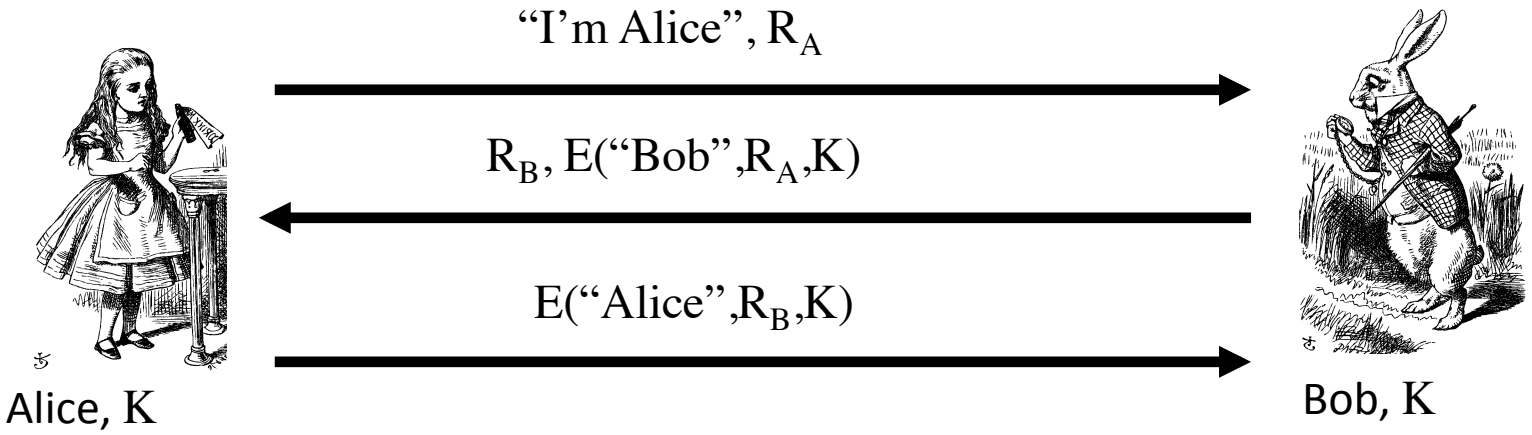
4. R_C, $E(R_B, K)$

Bob, K

Mutual Authentication

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

Symmetric Key Mutual Authentication

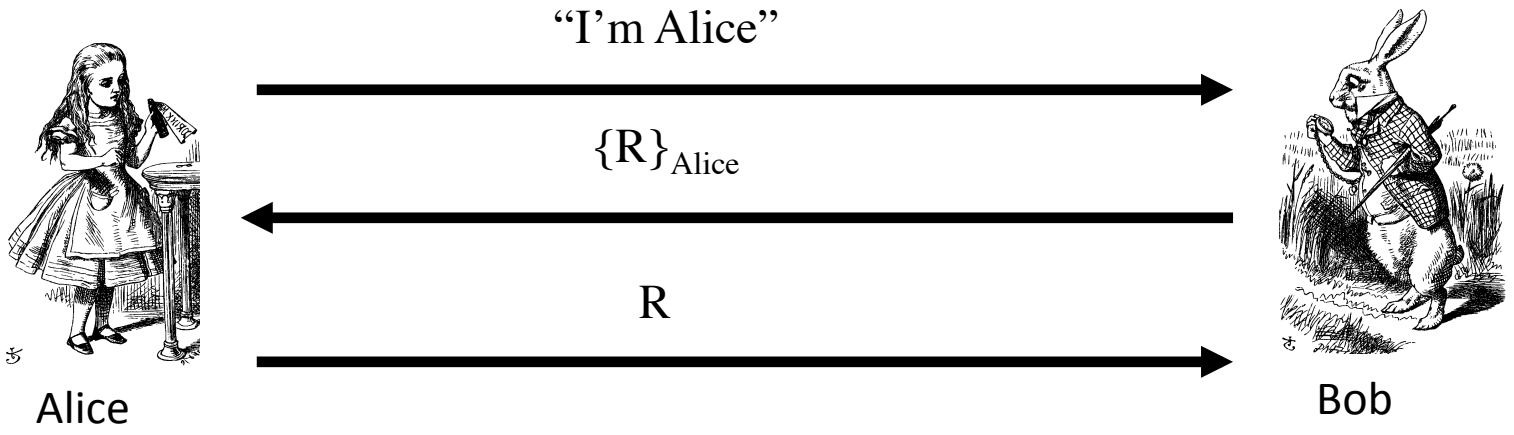


- Do these "insignificant" changes help?
- Yes!

Public Key Notation

- Encrypt M with Alice's public key: $\{\mathrm{M}\}_{\mathrm{Alice}}$
- Sign M with Alice's private key: $[\mathrm{M}]_{\mathrm{Alice}}$
- Then
  - $[\{\mathrm{M}\}_{\mathrm{Alice}}]_{\mathrm{Alice}} = \mathrm{M}$
  - $\{[\mathrm{M}]_{\mathrm{Alice}}\}_{\mathrm{Alice}} = \mathrm{M}$
- **Anybody** can use Alice's **public key**
- Only **Alice** can use her **private key**

Public Key Authentication



- Is this secure?
- Trudy can get Alice to decrypt anything!
  - So, should have two key pairs

Public Key Authentication

- Is this secure?
- Trudy can get Alice to sign anything!
  - Same a previous — should have two key pairs

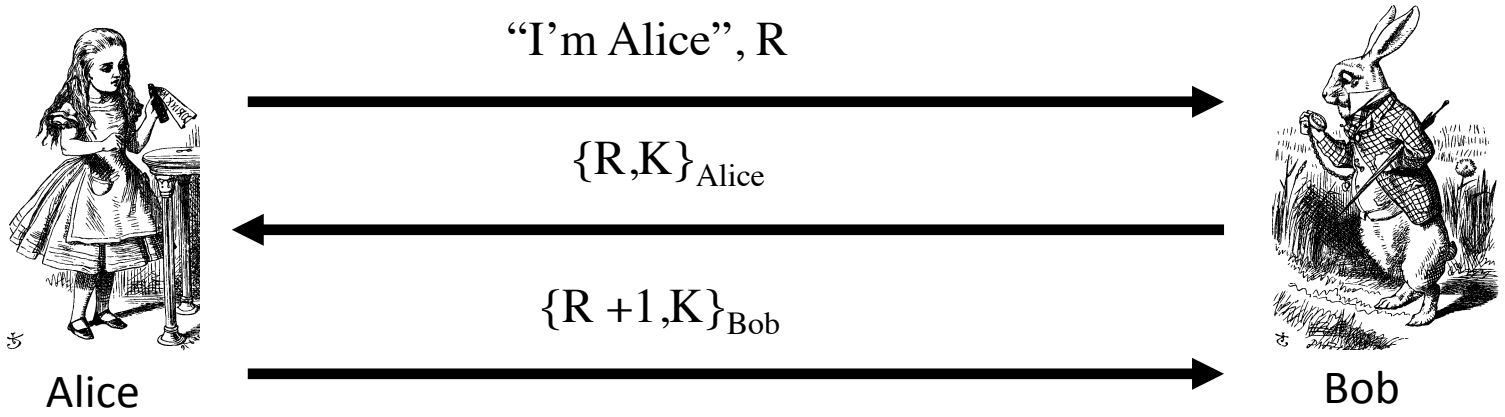
Public Keys

- Generally, a bad idea to use the same key pair for encryption and signing
- Instead, should have…
  - …one key pair for encryption/decryption…
  - …and a different key pair for signing/verifying signatures

Session Key

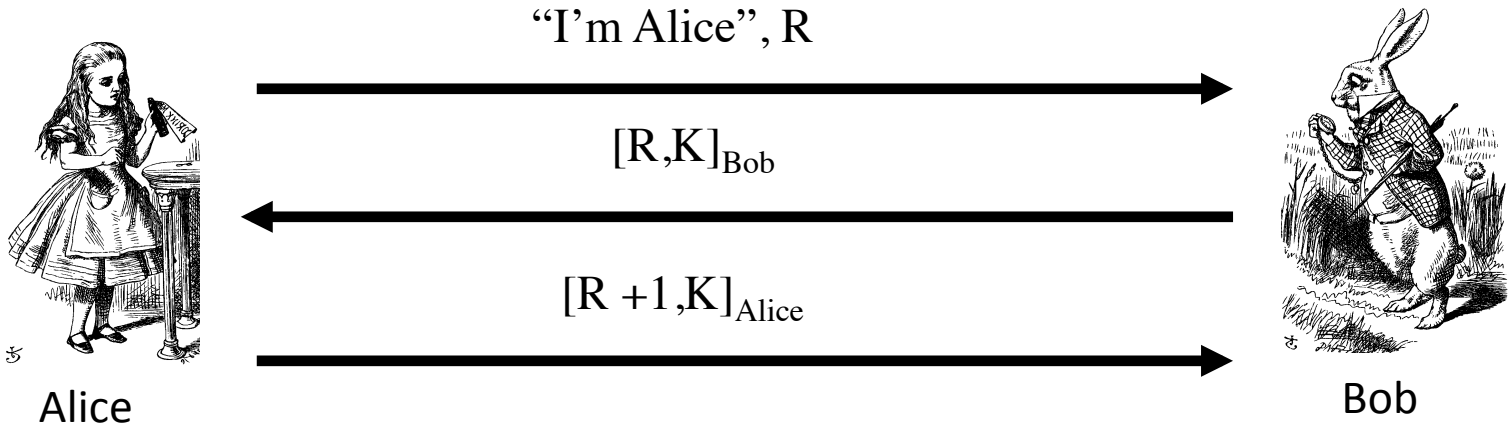
- Usually, a **session key** is required
  - I.e., a symmetric key for a particular session
  - Used for confidentiality and/or integrity
- How to authenticate and establish a session key (i.e., shared symmetric key)?
  - When authentication completed, want Alice and Bob to share a session key
  - Trudy cannot break the authentication…
  - …and Trudy cannot determine the session key

Authentication & Session Key



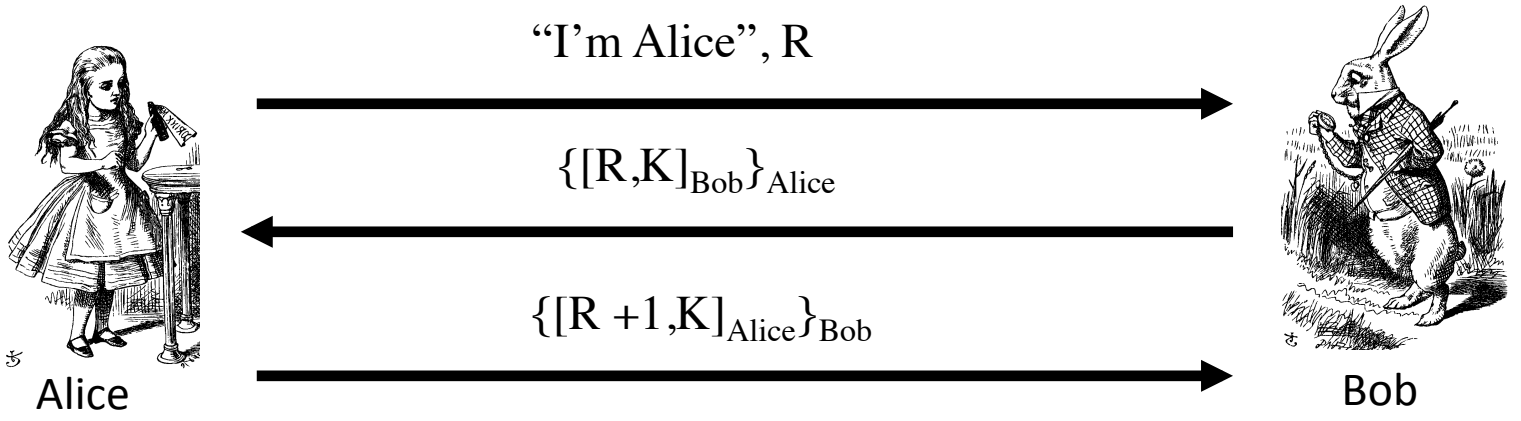
- Is this secure?
  - Alice is authenticated and session key is secure
  - Alice's "nonce", R, useless to authenticate Bob
  - The key K is acting as Bob's nonce to Alice
- No mutual authentication

Public Key Authentication and Session Key



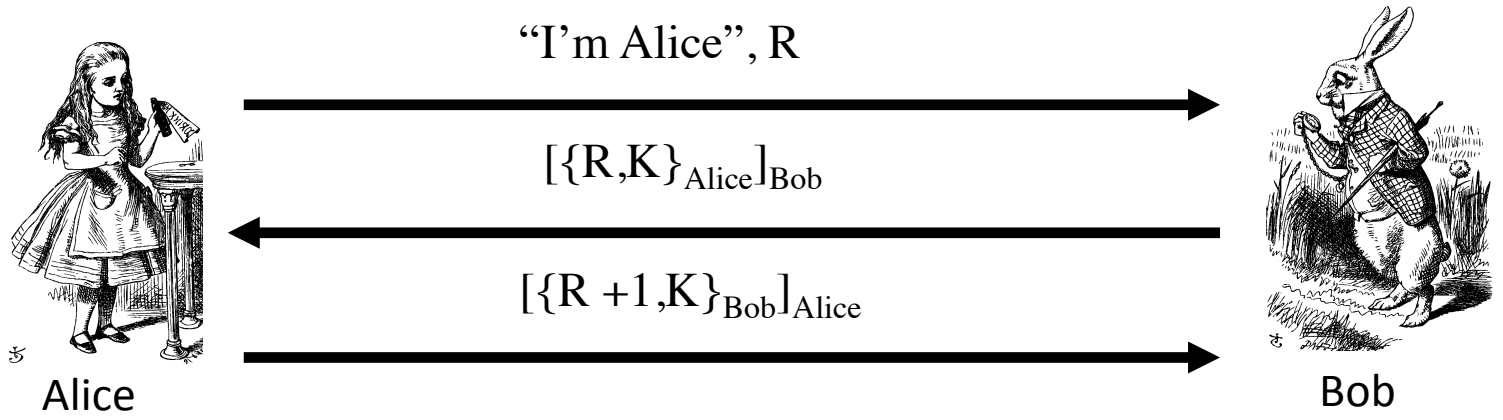
- Is this secure?
  - Mutual authentication (good), but…
  - … session key is not secret (very bad)

Public Key Authentication and Session Key



- Is this secure?
- Seems to be OK
- Mutual authentication and session key!

Public Key Authentication and Session Key



- Is this secure?
- Seems to be OK
  - Anyone can see $\{R,K\}_{Alice}$ and $\{R+1,K\}_{Bob}$

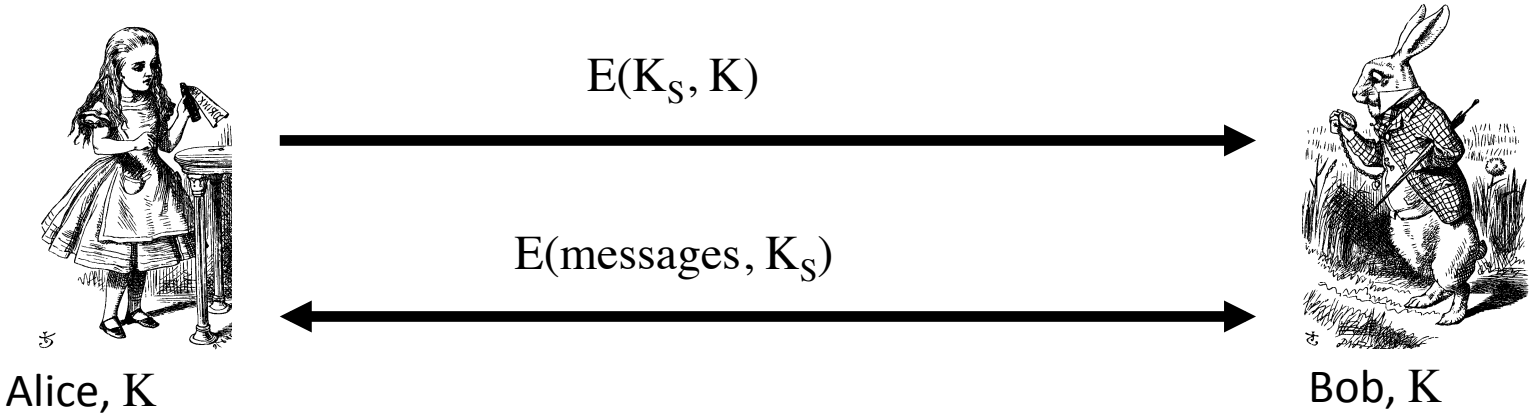
Perfect Forward Secrecy

- Consider this "issue"…
  - Alice encrypts message with shared key K and sends ciphertext to Bob
  - Trudy records ciphertext and later attacks Alice's (or Bob's) computer to recover K
  - Then Trudy decrypts recorded messages
- **Perfect forward secrecy (PFS):** Trudy cannot later decrypt recorded ciphertext
  - Even if Trudy gets key K or other secret(s)
- Is PFS possible?

Perfect Forward Secrecy

- Suppose Alice and Bob share key K
- For perfect forward secrecy, Alice and Bob cannot use K to encrypt
- Instead they must use a session key $\mathrm{K_S}$ and forget it after it's used
- Can Alice and Bob agree on session key $\mathrm{K_S}$ in a way that ensures PFS?

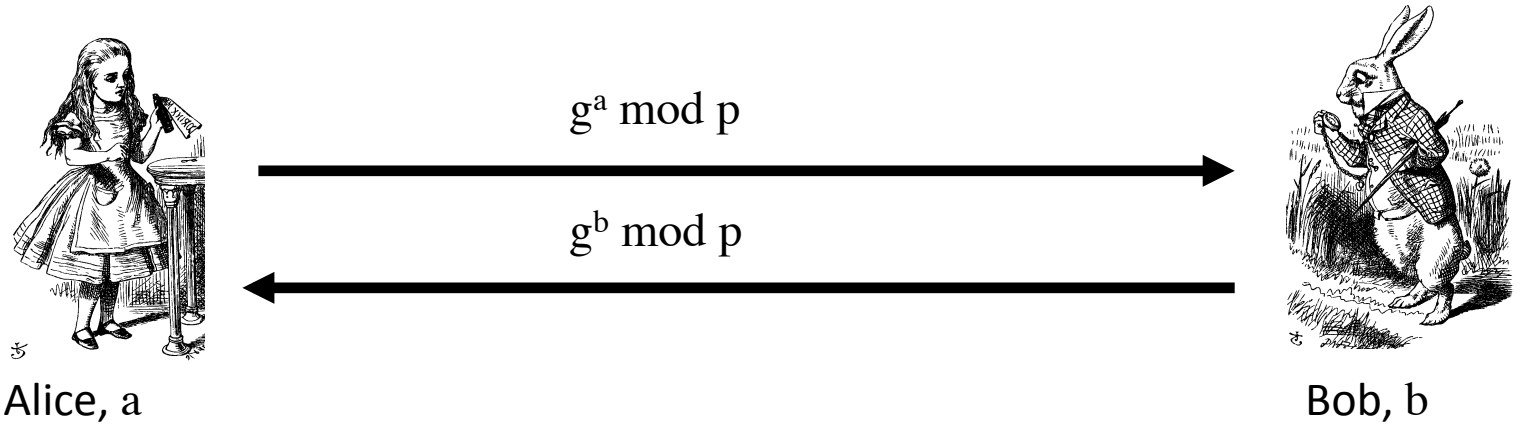
Naïve Session Key Protocol



- Trudy could record $E(K_S, K)$
- If Trudy later gets K then she can get K_S
  - Then Trudy can decrypt recorded messages

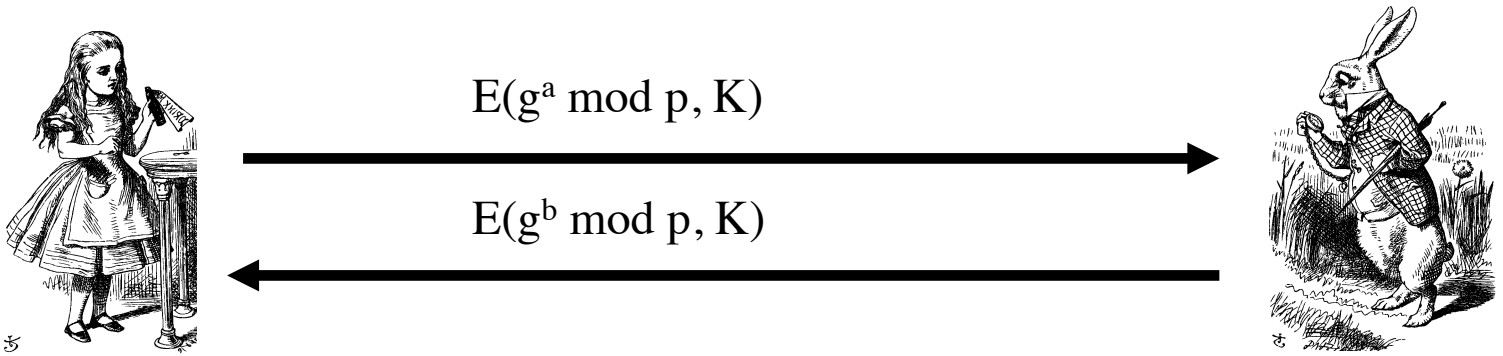
Perfect Forward Secrecy

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



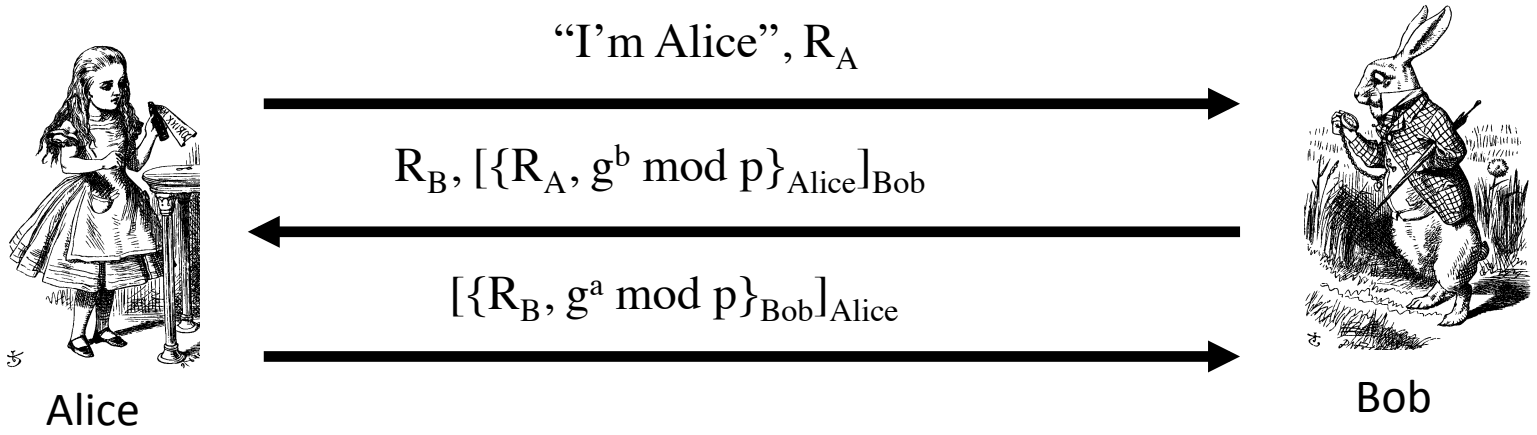
- But Diffie-Hellman is subject to MiM
- How to get PFS and prevent MiM?

Perfect Forward Secrecy



- Session key $K_S = g^{ab} \bmod p$
- Alice **forgets** a, Bob **forgets** b
- So-called **Ephemeral Diffie-Hellman**
- Neither Alice nor Bob can later recover K_S
- Are there other ways to achieve PFS?

Mutual Authentication, Session Key and PFS

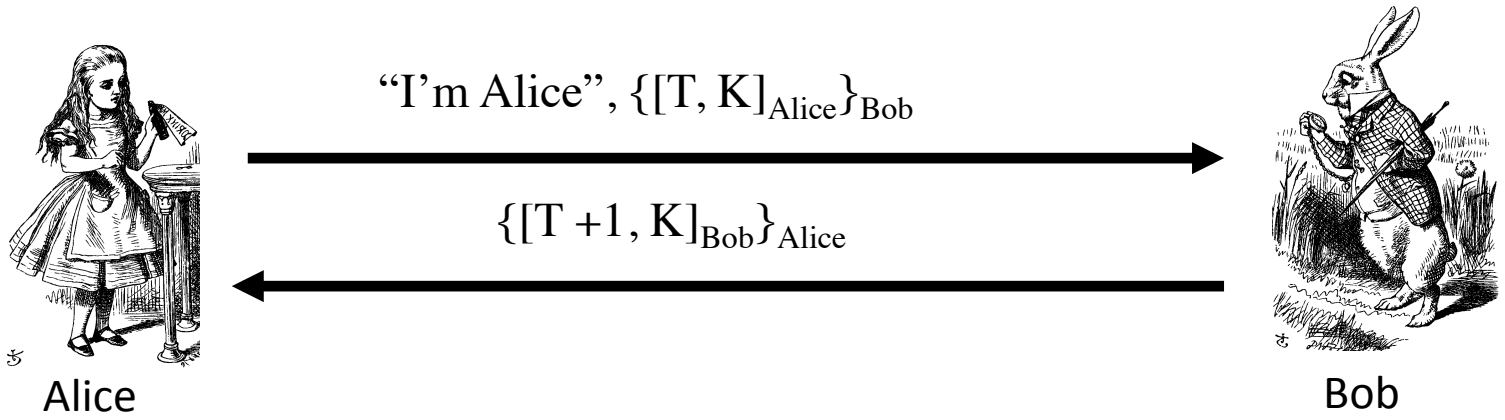


- Session key is $K = g^{ab} \bmod p$
- Alice forgets a and Bob forgets b
- If Trudy later gets Bob's and Alice's secrets, she cannot recover session key K

Timestamps

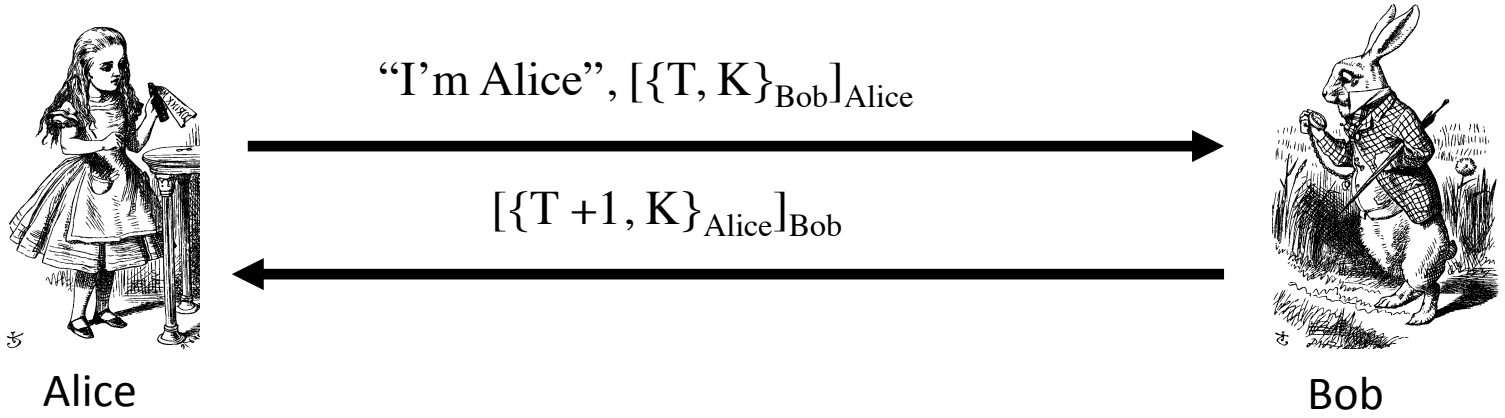
- A timestamp T is derived from current time
- Timestamps used in some security protocols
  - Kerberos, for example
- Timestamps reduce number of msgs (good)
  - Like a nonce that both sides know in advance
- "Time" is a security-critical parameter (bad)
- Clocks never exactly the same, so must allow for **clock skew** — creates risk of replay
  - How much clock skew is enough?

Public Key Authentication with Timestamp T



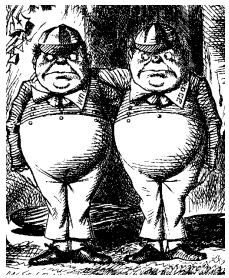
- Secure mutual authentication?
- Session key?
- Seems to be OK

Public Key Authentication with Timestamp T



- Secure authentication and session key?
- Trudy can use Alice's public key to find $\{T, K\}_{Bob}$ and then…

Public Key Authentication with Timestamp T



Trudy

Bob

$$\text{“I'm Trudy”}, [\{T, K\}_{Bob}]_{Trudy}$$

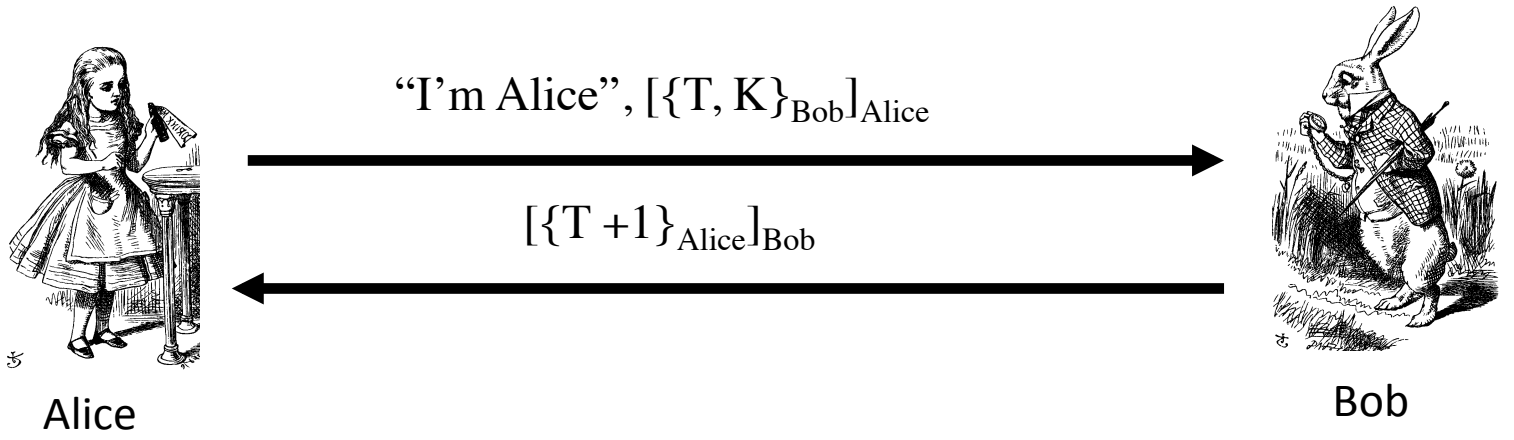
$$[\{T+1, K\}_{Trudy}]_{Bob}$$

- Trudy obtains Alice-Bob session key K
- Note: Trudy must act within clock skew

Public Key Authentication

- Sign and encrypt with nonce…
  - **Secure**
- Encrypt and sign with nonce…
  - **Secure**
- Sign and encrypt with timestamp…
  - **Secure**
- Encrypt and sign with timestamp…
  - **Insecure**
- Protocols can be subtle!

Public Key Authentication with Timestamp T



- Is this "encrypt and sign" secure?
  - Yes, seems to be OK
- Does "sign and encrypt" also work here?