Protocol

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Protocol

- Human protocols — the rules followed in human interactions
  - Example: Asking a question in class
- Networking protocols — rules followed in networked communication systems
  - Examples: HTTP, FTP, etc.
- Security protocol — the (communication) rules followed in a security application
  - Examples: SSH, SSL, IPSec, Kerberos, etc.

Protocols

- Protocol flaws can be very ***subtle***
- Several well-known security protocols have significant flaws
  - Including WEP, GSM, and IPSec
- Implementation errors can also occur
  - Heartbleed
- Not easy to get protocols right…

Ideal Security Protocol

- Must satisfy security requirements
  - Requirements need to be precise
- Efficient
  - Minimize computational requirement
  - Minimize bandwidth usage, delays…
- Robust
  - Works when attacker tries to break it
  - Works if environment changes (slightly)
- Easy to implement, easy to use, flexible…
- Difficult to satisfy all of these!

Authentication Protocols

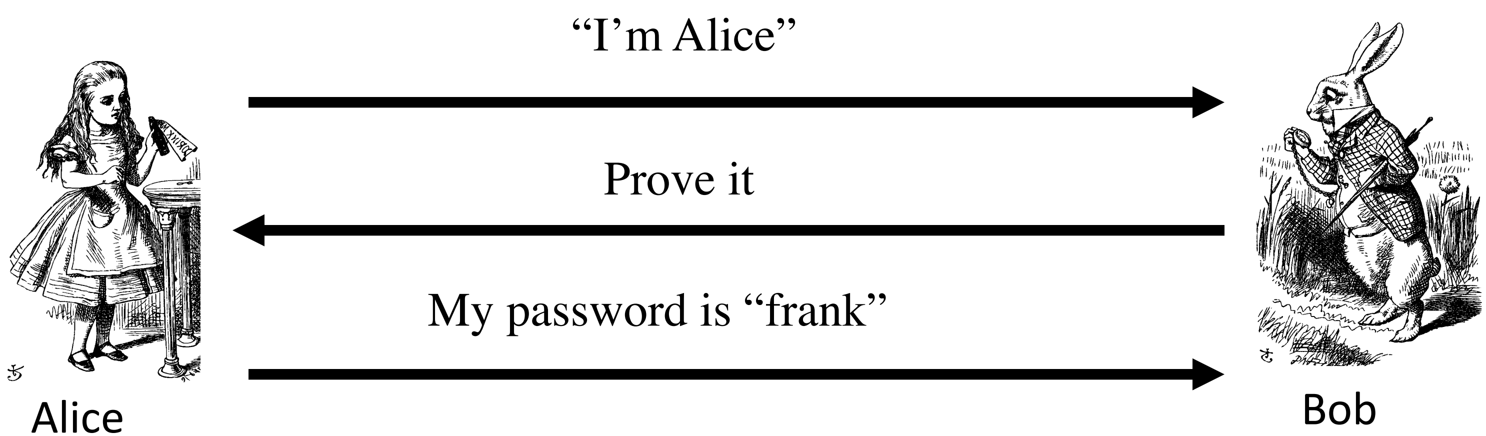
Authentication

- 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
  - Public keys, symmetric keys, hash functions, …
  - Anonymity, plausible deniability, perfect forward secrecy, etc.

Authentication

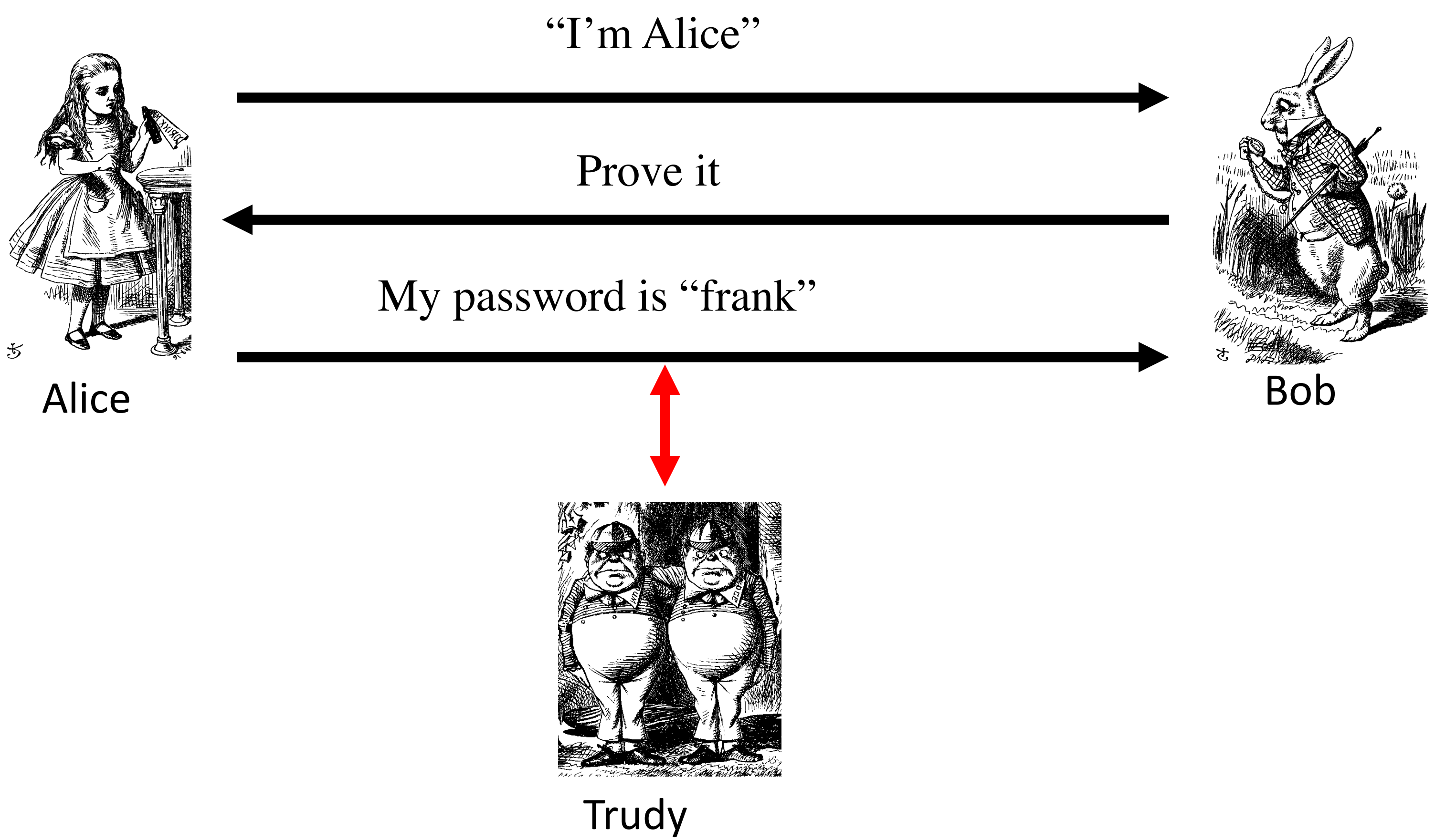
- Authentication on a stand-alone computer is relatively simple
  - For example, hash a password with a salt
- Authentication over a network is challenging
  - Attacker can passively observe messages
  - Attacker can replay messages
  - Active attacks possible (insert, delete, change)

Simple Authentication

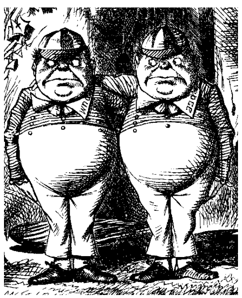


- Simple and may be OK for standalone system
- But highly insecure for networked system
  - Subject to a **replay** attack (next 2 slides)
  - Also, Bob must know Alice's password

Authentication Attack



Authentication Attack



Trudy

“I’m Alice”

Prove it

My password is “frank”

Bob

- 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

Alice

"I'm Alice" →

← Prove it

h(Alice's password) →

Bob

- This approach hides Alice's password
  - From both Bob and Trudy
- But still subject to replay attack

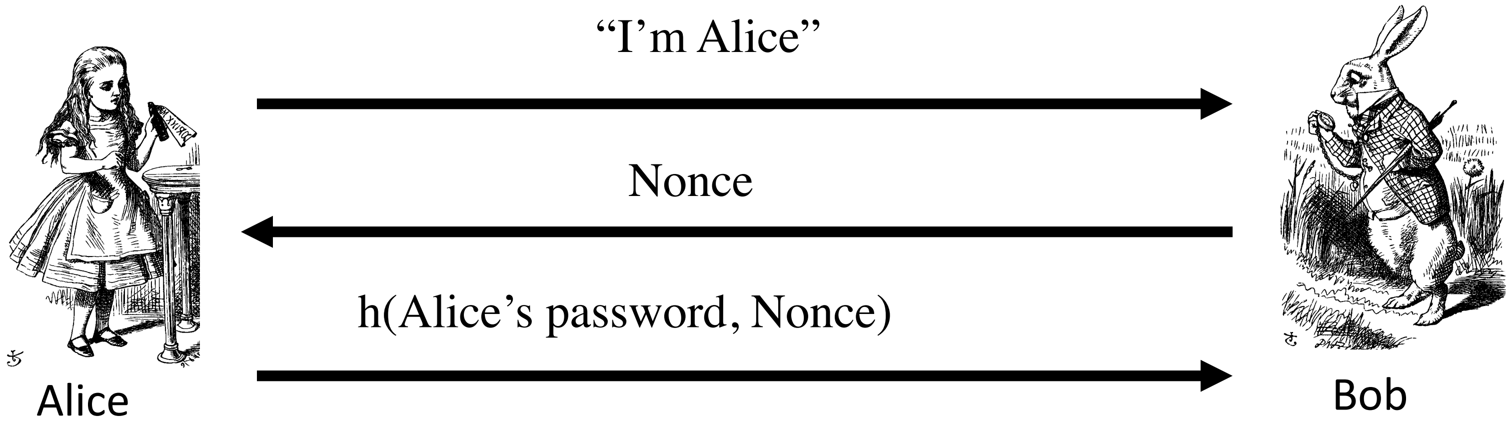
Challenge-Response

- 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?

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
  - Can we do better?

Symmetric Key Notation

- Encrypt plaintext P with key K

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

- Decrypt ciphertext C with key K

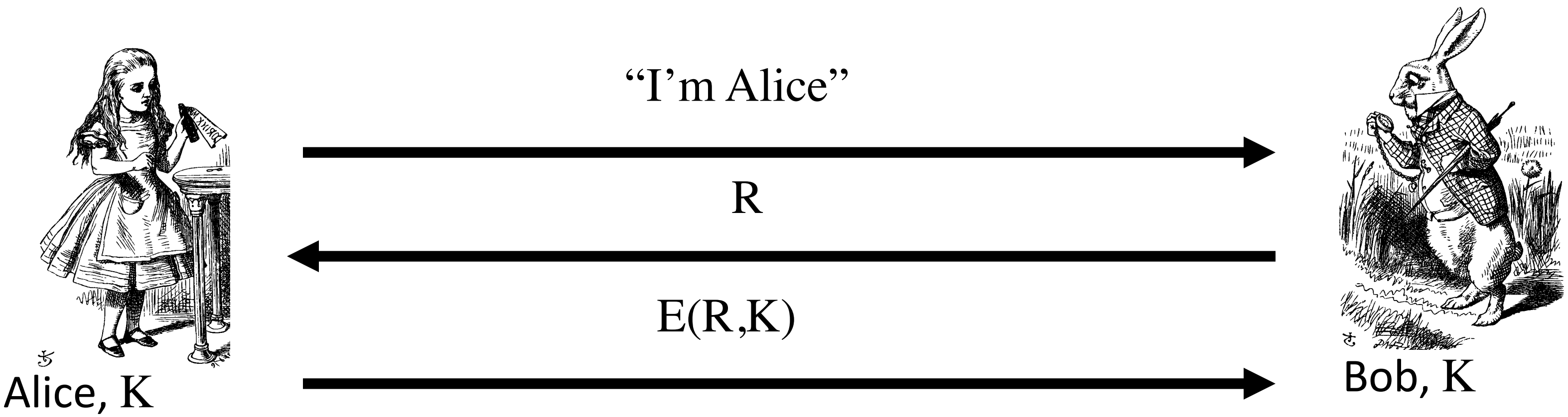
$$P = D(C,K)$$

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

Authentication: Symmetric Key

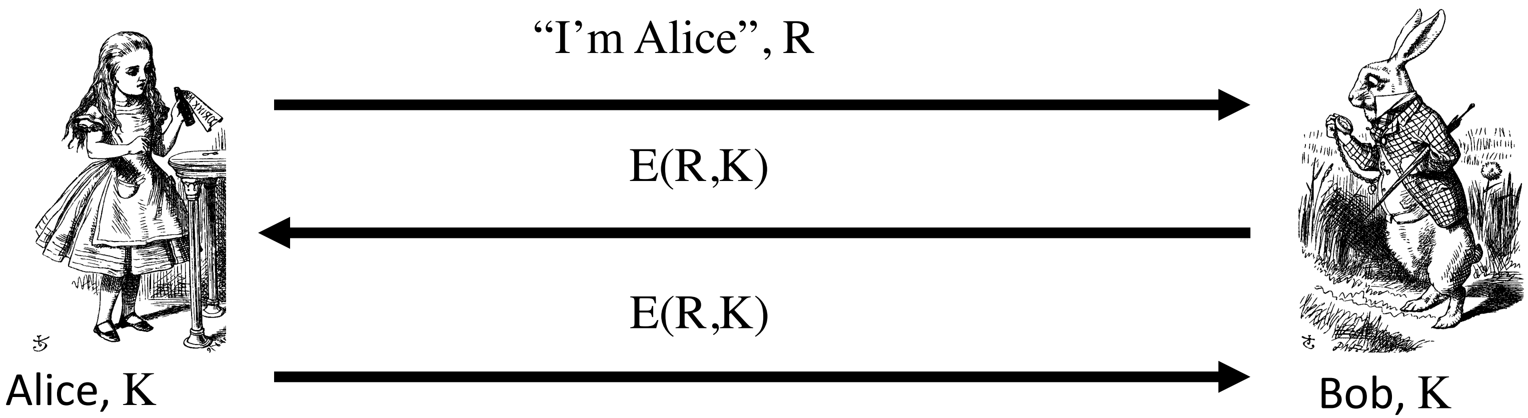
- Alice and Bob share symmetric key K
- Key K known only to Alice and Bob
- Authenticate by proving knowledge of shared symmetric key
- How to accomplish this?
  - Cannot reveal key, must not allow replay (or other) attack, must be verifiable, …

Authenticate Alice Using Symmetric Key



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

Mutual Authentication?

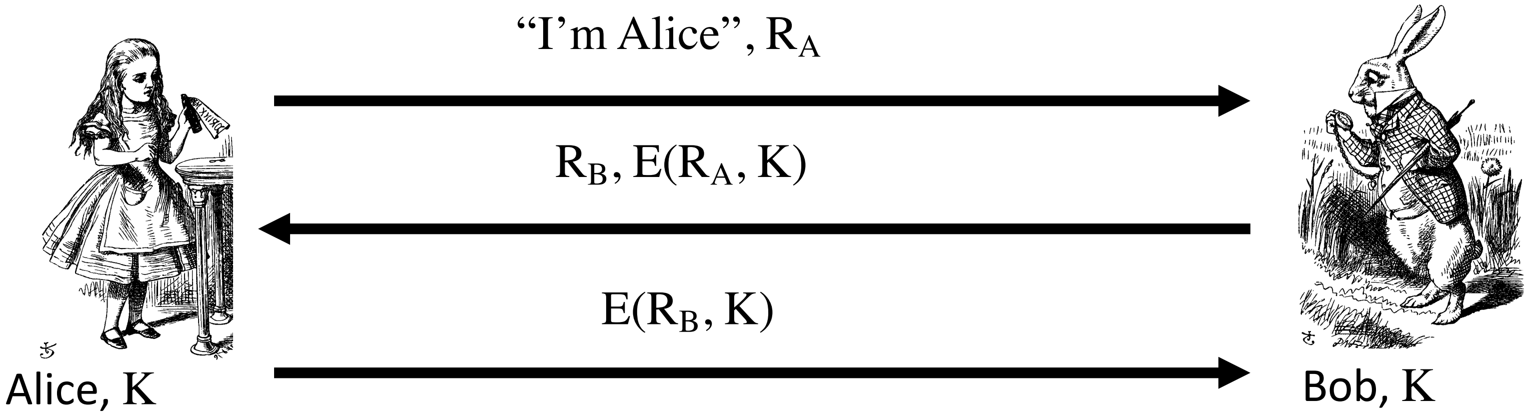


- What's wrong with this picture?

Mutual Authentication

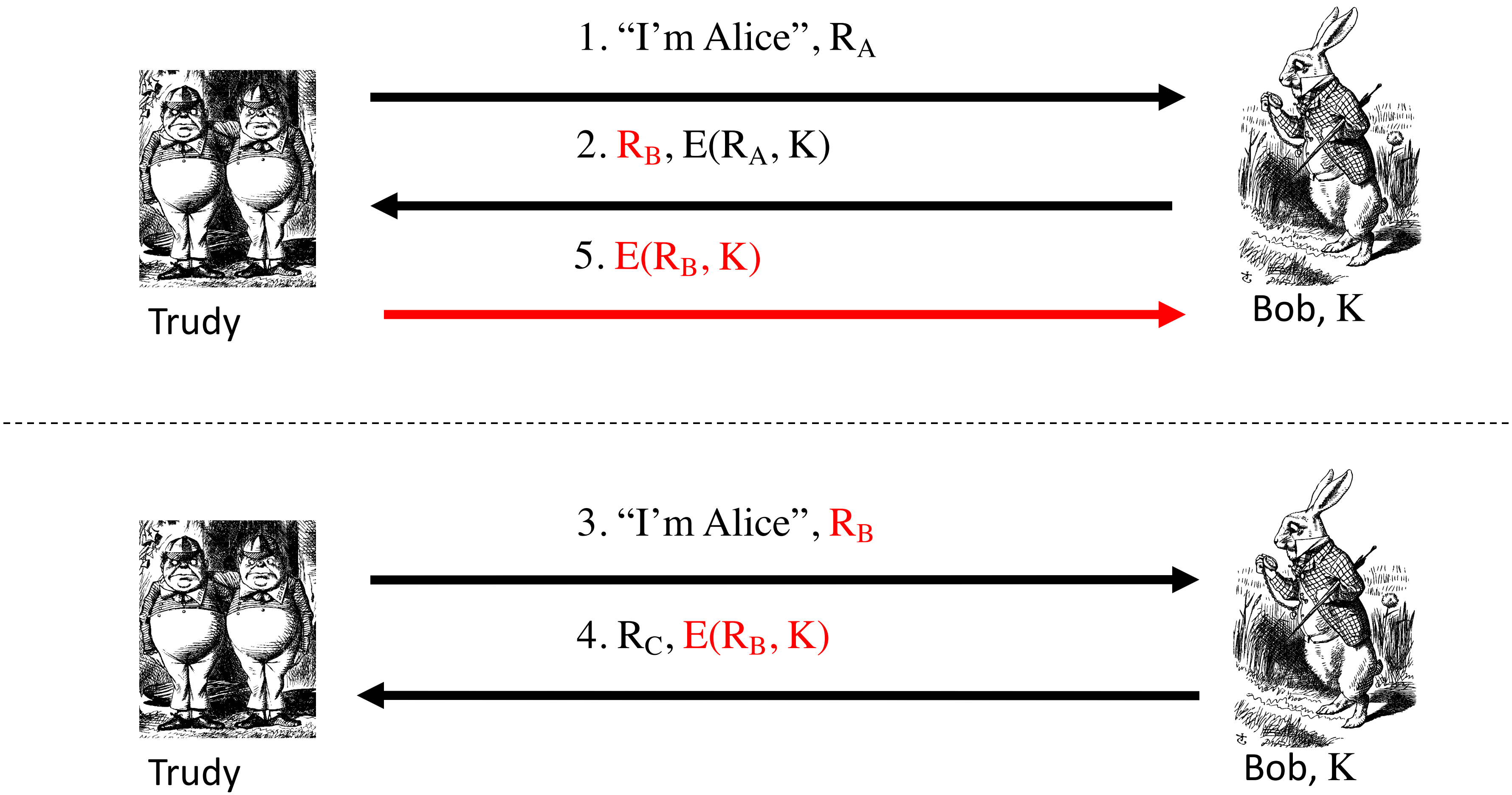
- Since we have a secure one-way authentication protocol…
- The obvious thing to do is to use the protocol twice
  - Once for Bob to authenticate Alice
  - Once for Alice to authenticate Bob
- This has got to work…

Mutual Authentication



- This provides mutual authentication...
- ...or does it? Subject to **reflection** attack
  - Next slide

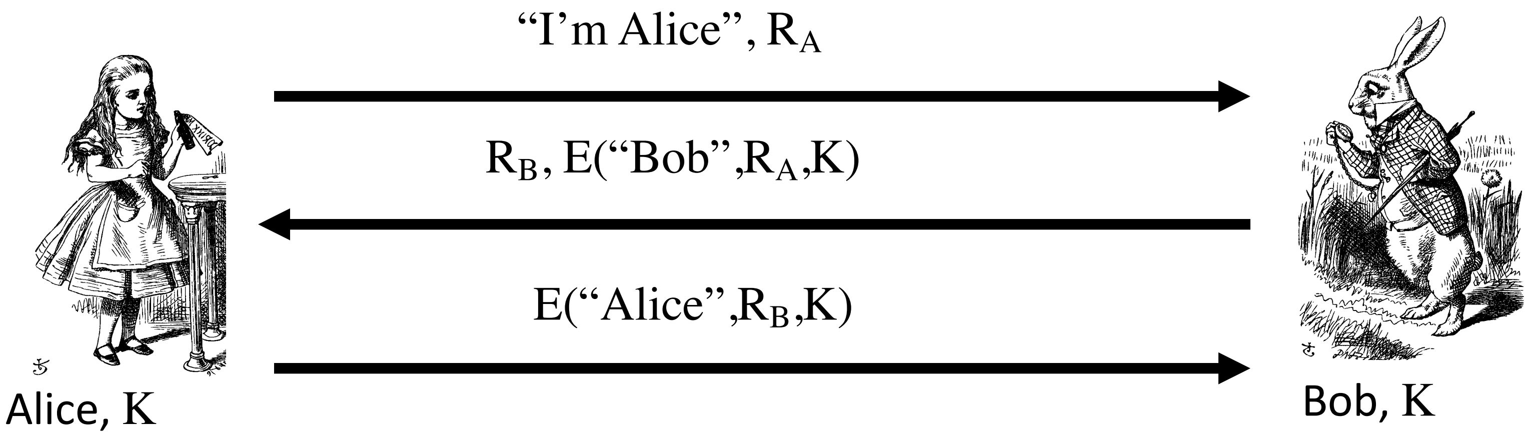
Mutual Authentication Attack



Mutual Authentication

- Our one-way authentication protocol is **not** secure for mutual authentication
  - Protocols are subtle!
  - In this case, “obvious” solution is not 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: $\{M\}_{\text{Alice}}$
- Sign M with Alice's private key: $[M]_{\text{Alice}}$
- Then
  - $[\{M\}_{\text{Alice}}]_{\text{Alice}} = M$
  - $\{[M]_{\text{Alice}}\}_{\text{Alice}} = M$
- **Anybody** can use Alice's **public key**
- Only **Alice** can use her **private key**

Public Key Authentication

“I’m Alice”

$\{R\}_{\text{Alice}}$

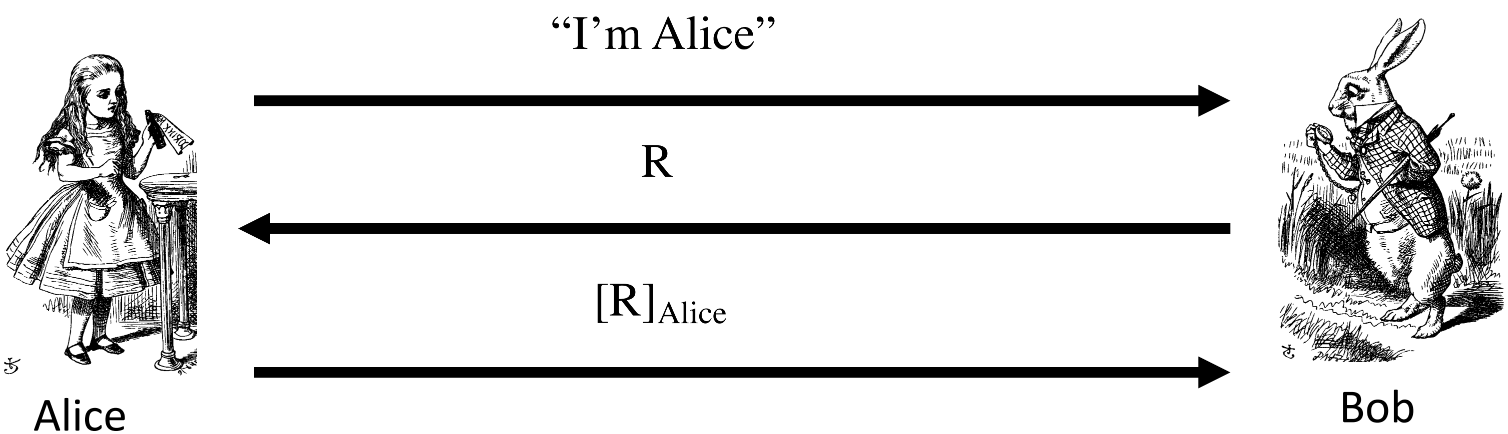
R

Alice

Bob

- Is this secure?
- But usually use two key pairs (why?)

Public Key Authentication



- Is this secure?
- But usually use two key pairs (why?)

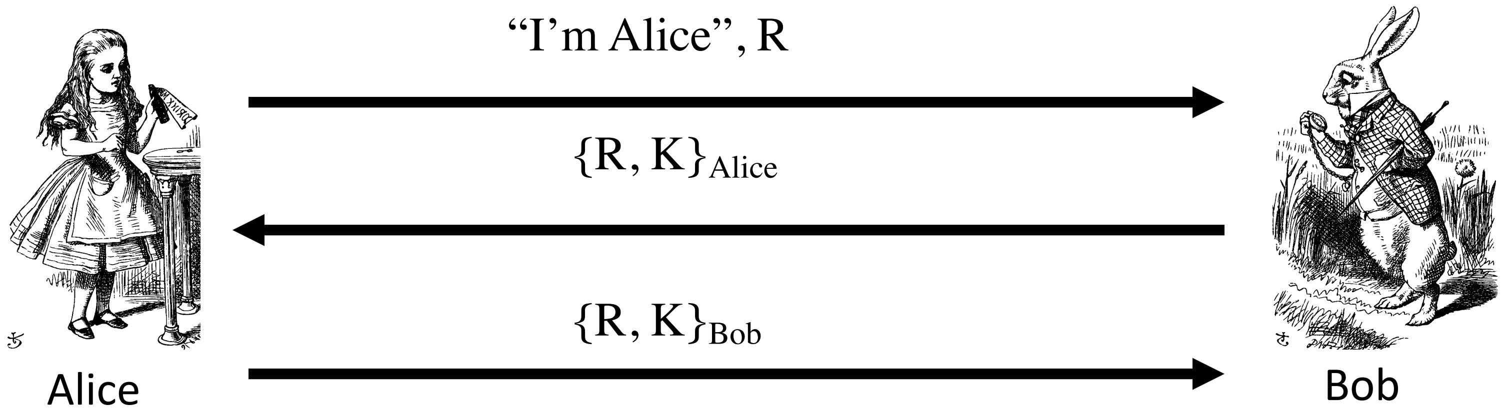
Public Keys

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

Session Key

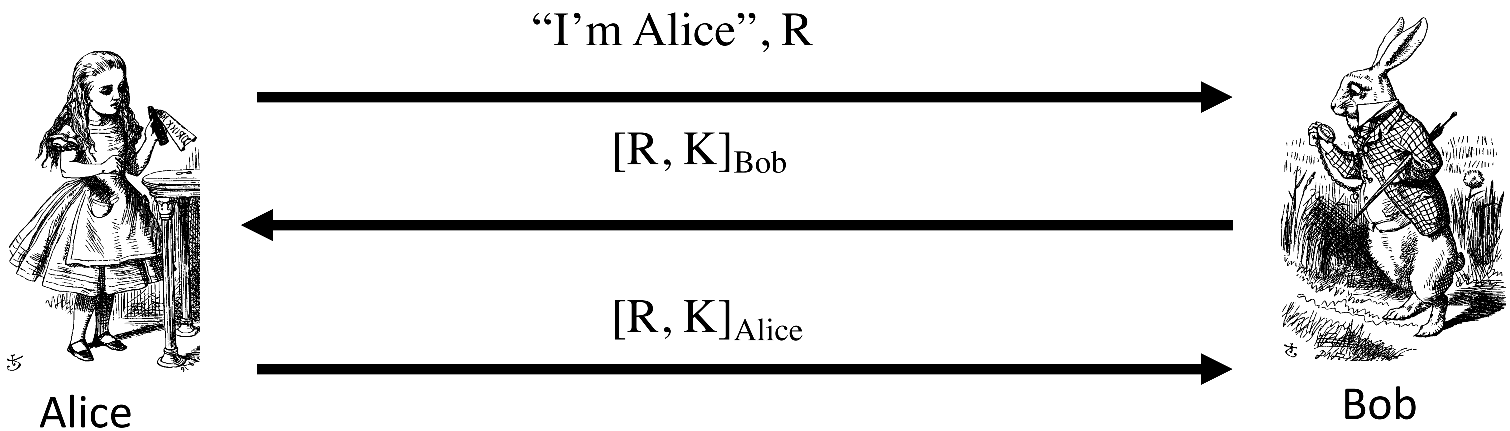
- Usually, a **session key** is required
  - A symmetric key for current session
  - Used for confidentiality and/or integrity
- Ideal case
  - When authentication completed, Alice and Bob share a session key
  - Trudy cannot break the authentication…
  - …***and*** Trudy cannot determine the session key

Authentication & Session Key



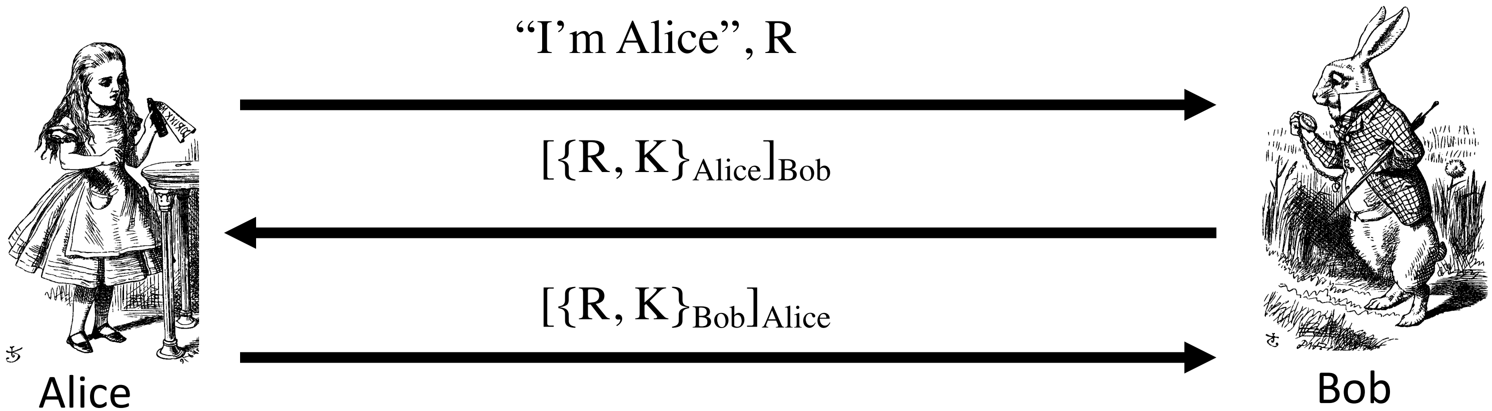
- Is this secure?
    - Alice is authenticated and session key is secure
    - Alice’s “nonce”, R, useless to authenticate Bob
- No mutual authentication

Public Key Authentication and Session Key



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

Public Key Authentication and Session Key



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

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 K_S and forget it after it's used
- Can Alice and Bob agree on session key K_S in a way that provides PFS?

Naïve Session Key Protocol

$E(K_S, K)$

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

Alice, K

Bob, K

- Trudy could record $E(K_S, K)$
- If Trudy later gets K then she can get K_S
  - Then Trudy can decrypt recorded messages
- ***No*** perfect forward secrecy in this case

Naïve Session Key Protocol

Alice, K

$E(K_S, K)$ →

$E(\text{messages}, K_S)$ ↔

Bob, K

- Trudy could record $E(K_S, K)$
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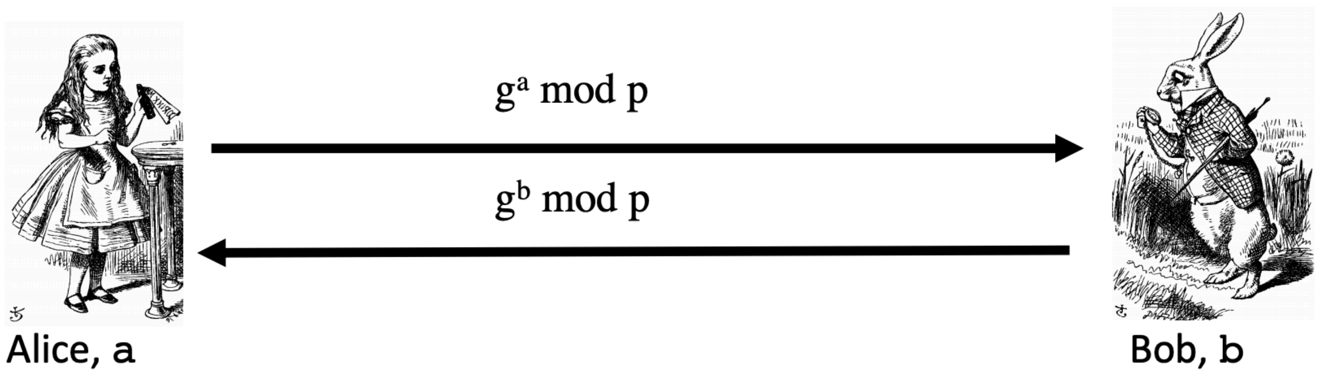
Diffie-Hellman

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



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

In case you already forgot…

Diffie–Hellman -- An Example

1. Alice and Bob publicly agree to use a modulus $p = 23$ and base $g = 5$ (which is a primitive root modulo 23).
2. Alice chooses a secret integer $a = 4$, then sends Bob $A = g^a \bmod p$
   - $A = 5^4 \bmod 23 = 4$
3. Bob chooses a secret integer $b = 3$, then sends Alice $B = g^b \bmod p$
   - $B = 5^3 \bmod 23 = 10$
4. Alice computes $s = B^a \bmod p$
   - $s = 10^4 \bmod 23 = 18$
5. Bob computes $s = A^b \bmod p$
   - $s = 4^3 \bmod 23 = 18$
6. Alice and Bob now share a secret (the number 18).

Both Alice and Bob have arrived at the same values because under mod p,

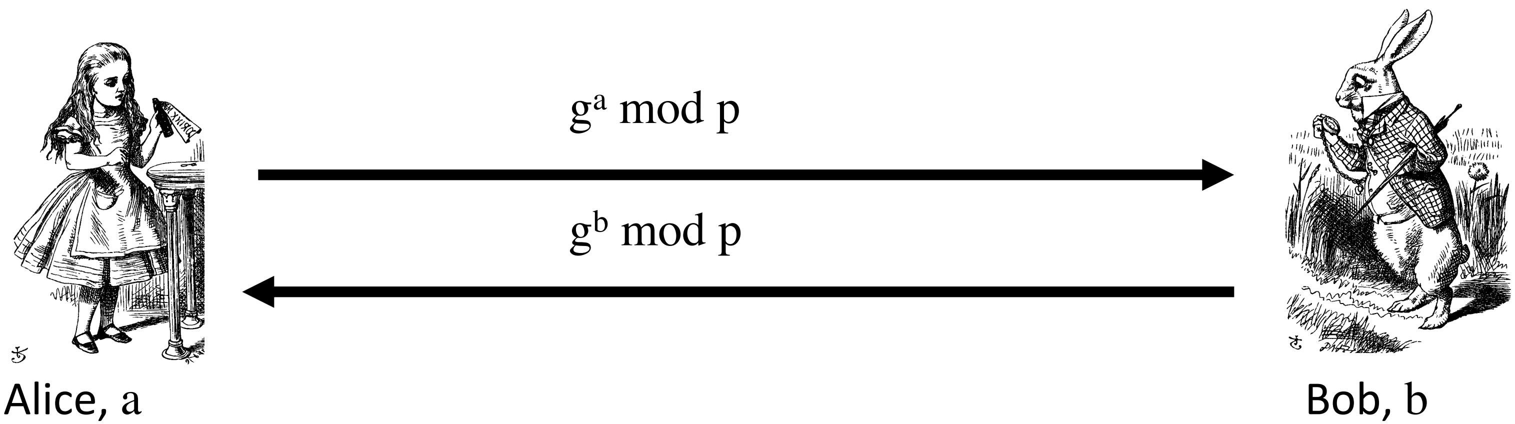
$$A^b \bmod p = g^{ab} \bmod p = g^{ba} \bmod p = B^a \bmod p$$

More specifically,

$$(g^a \bmod p)^b \bmod p = (g^b \bmod p)^a \bmod p$$

Perfect Forward Secrecy

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



Perfect Forward Secrecy

$E(g^a \bmod p, K)$ →

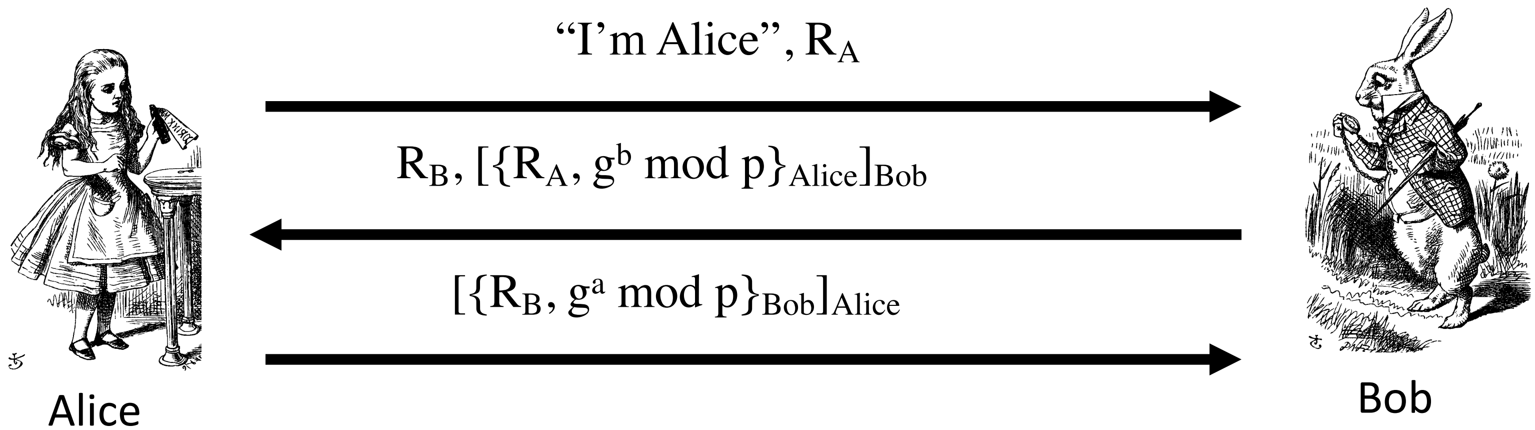
← $E(g^b \bmod p, K)$

Alice: K, a

Bob: K, b

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

Real-World Protocols

- Some real secure protocols
  - SSH — relatively simple & useful protocol
    - Mutual authentication, session key and PFS
  - SSL — practical security on the Web
  - IPSec — security at the IP layer
  - WEP — “Swiss cheese” of security protocols
  - GSM — mobile phone (in)security