CHAPTER 9
SIMPLE AUTHENTICATION PROTOCOLS

SIMPLE SECURITY PROTOCOL

AUTHENTICATION PROTOCOLS

ZERO KNOWLEDGE PROOFS

THE BEST AUTHENTICATION PROTOCOL?

PROTOCOLS

- 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 protocols — the (communication) rules followed in a security application
  - Examples: SSL, IPSec, Kerberos, etc.

PROTOCOLS

- Protocol flaws can be very subtle
- Several well-known security protocols have serious flaws
  - Including WEP, GSM and even IPSec
  - Implementation errors can occur
    - Such as IE implementation of SSL
- Not easy to get protocols right…

IDEAL SECURITY PROTOCOL

1. Satisfies security requirements
   - Requirements must be precise
2. Efficient
   - Minimize computational requirement — in particular, costly public key operations
   - Minimize delays/bandwidth
3. Not fragile
   - Must work when attacker tries to break it
   - Works even if environment changes
4. Easy to use and implement, flexible, etc.

- Difficult to satisfy all of these!

SIMPLE SECURITY PROTOCOLS

SECURE ENTRY TO NSA

1. Insert badge into reader
2. Enter PIN
3. Correct PIN?

    Yes? Enter

    No? Get shot by security guard

ATM MACHINE PROTOCOL

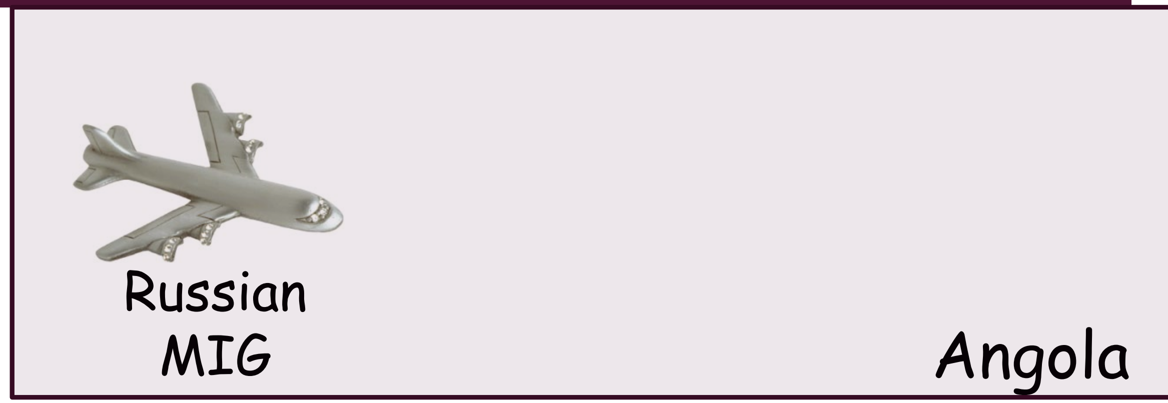
1. Insert ATM card
2. Enter PIN
3. Correct PIN?

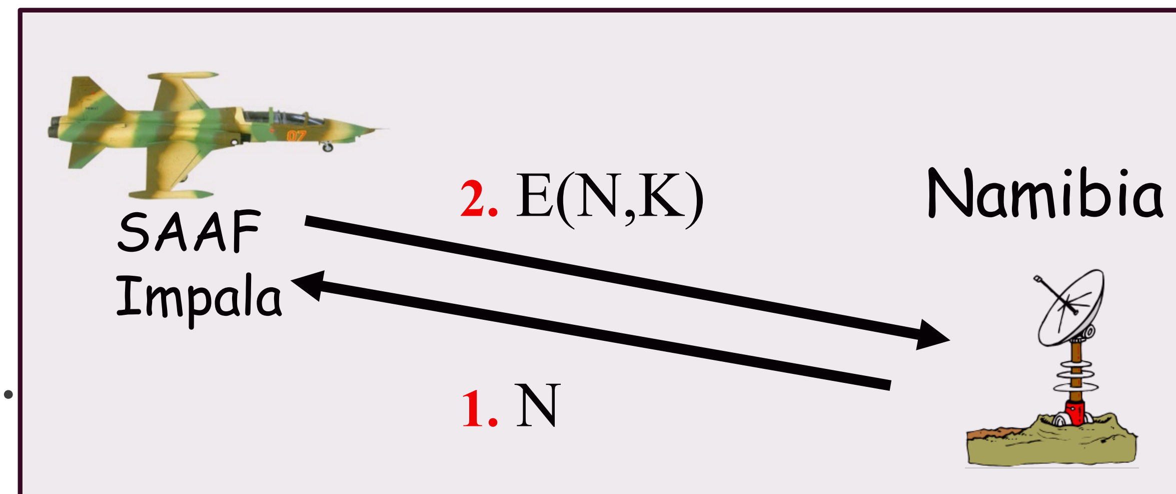
    Yes? Conduct your transaction(s)

    No? Machine eats card

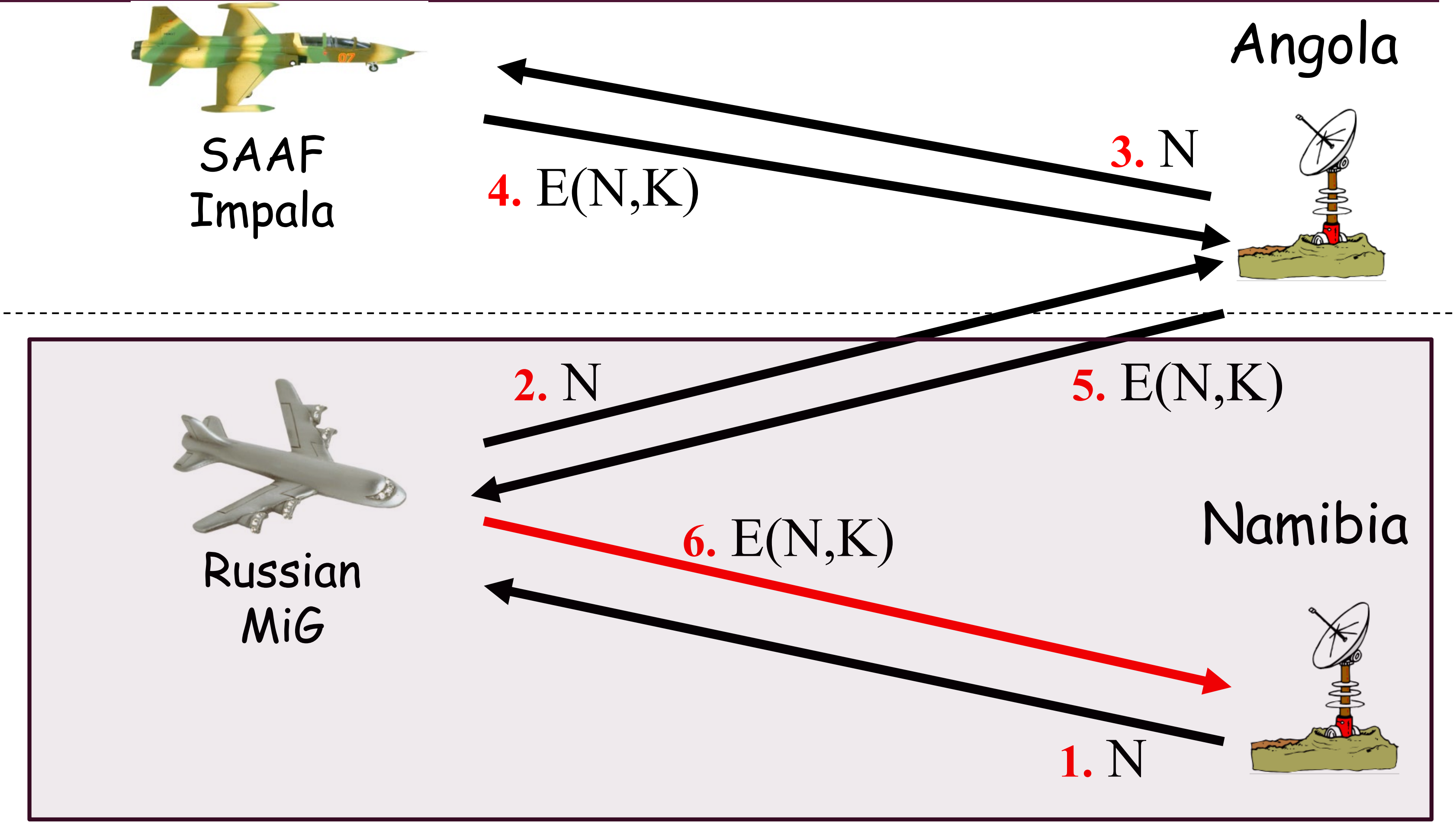
IDENTIFY FRIEND OR FOE (IFF)

- Military needs many specialized protocols
- Many cases, it could recognize friends as enemies, or ….





MIG IN THE MIDDLE



AUTHENTICATION PROTOCOLS

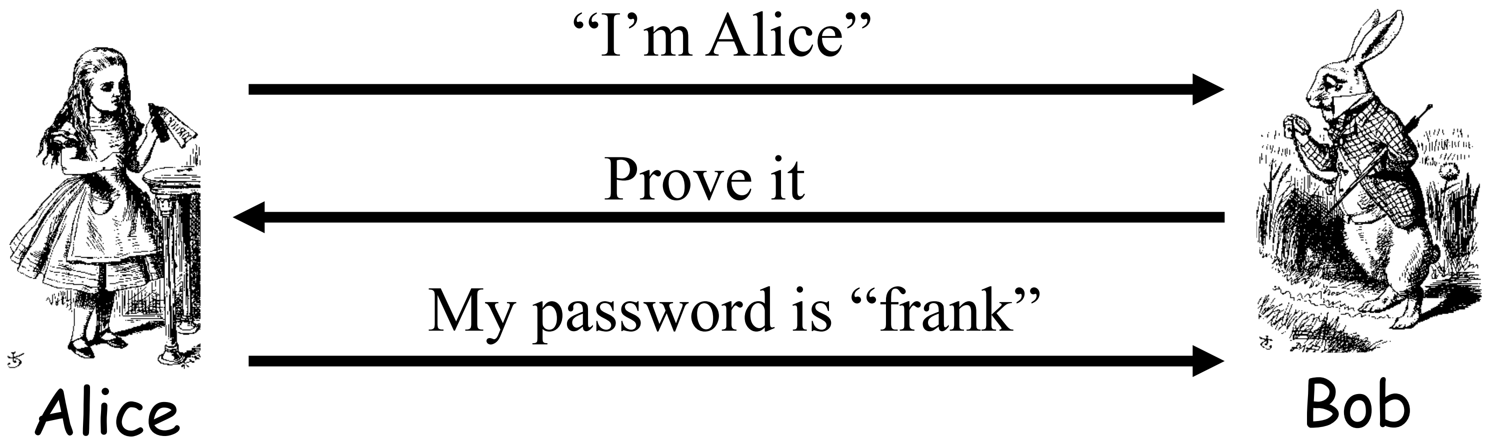
AUTHENTICATION

- 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)
- 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.

AUTHENTICATION

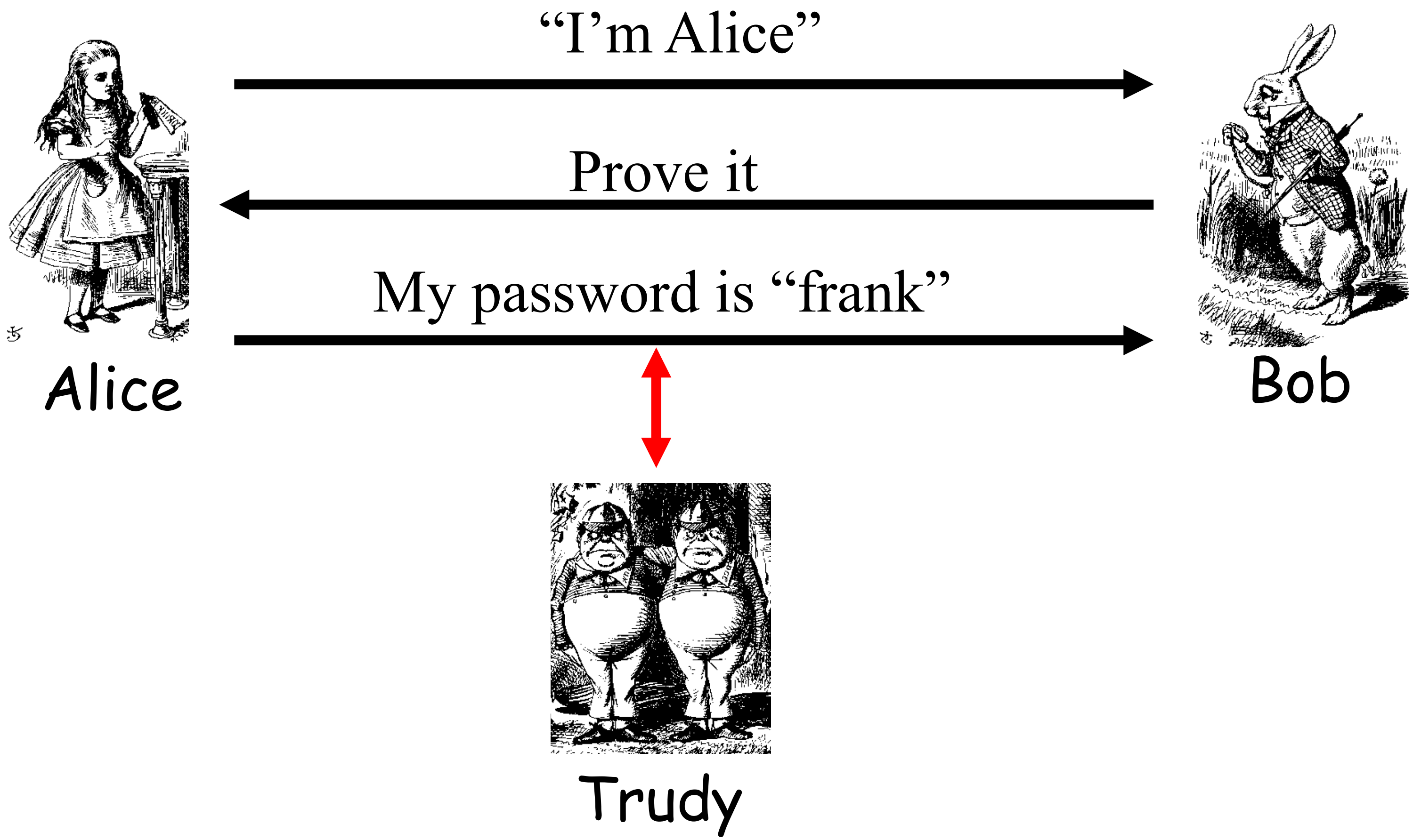
- Authentication on a stand-alone computer is relatively simple
  - "Secure path" is the primary issue
  - Main concern is an attack on authentication software (we discuss software attacks later)
- Authentication over a network is much more complex
  - Attacker can passively observe messages
  - Attacker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

SIMPLE AUTHENTICATION

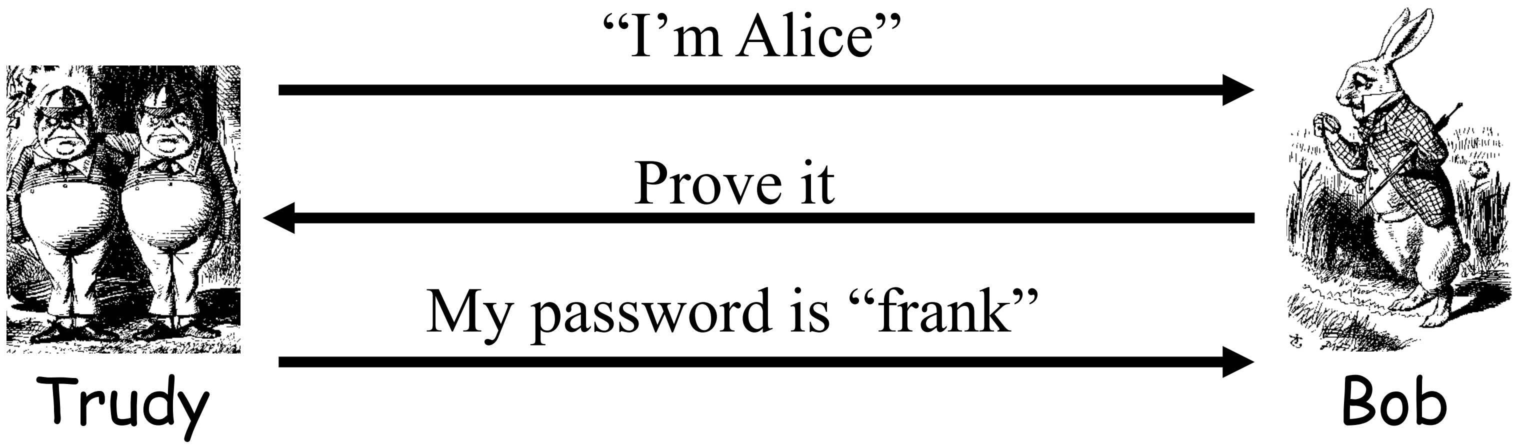


- Simple and may be OK for standalone system
- But insecure for networked system
  - Subject to a replay attack (next 2 slides)
  - Bob must know Alice's password

AUTHENTICATION ATTACK



AUTHENTICATION ATTACK



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

SIMPLE AUTHENTICATION

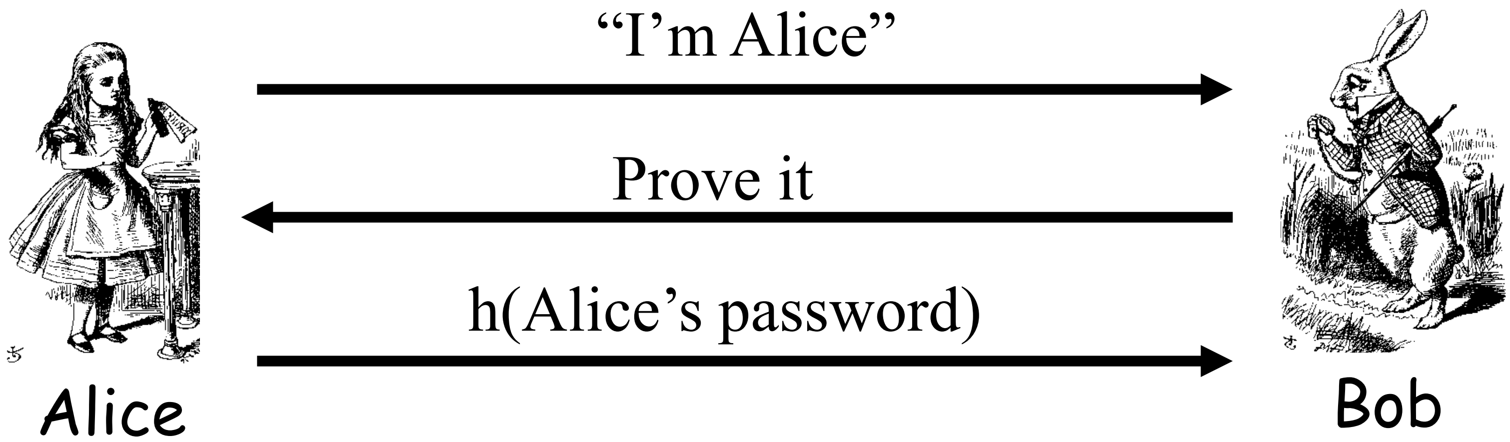
Alice

I’m Alice, My password is “frank”

Bob

- More efficient…
- But same problem as previous version
  - Replay attack

BETTER AUTHENTICATION



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

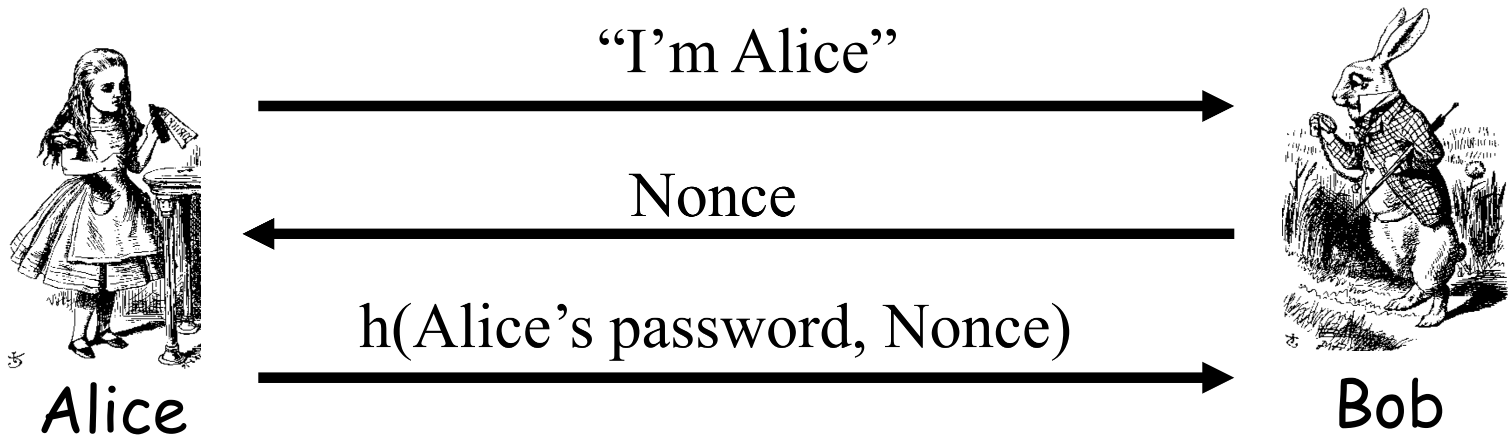
CHALLENGE-RESPONSE

- 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

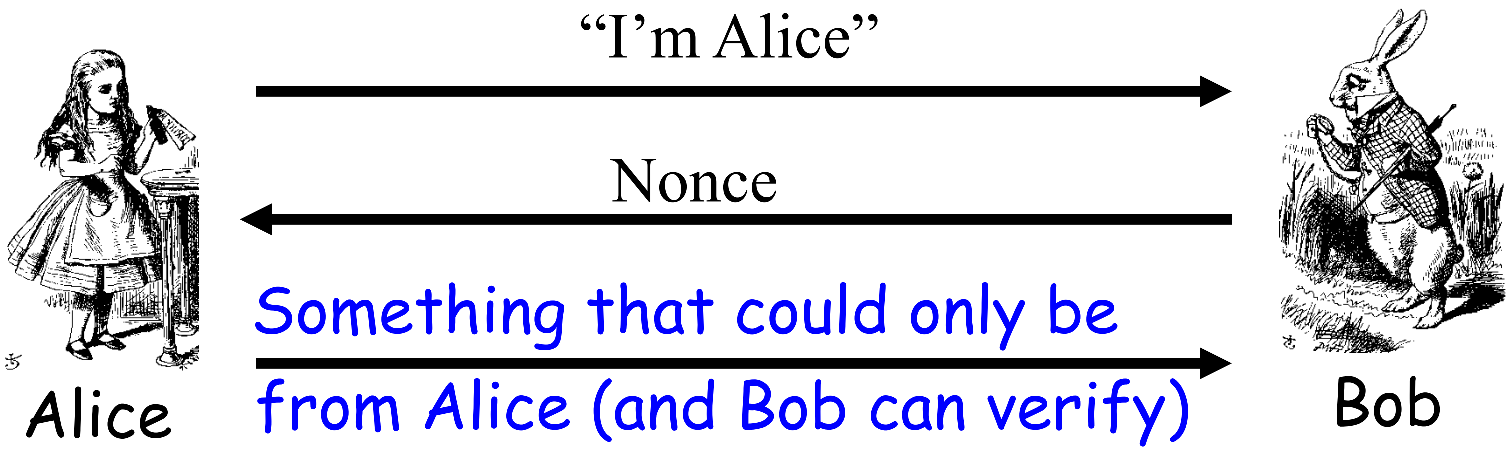
- To ensure freshness, can employ a **nonce**
  - Nonce == number used **once**
- What to use for nonces?
  - That is, what is the challenge?
- What should Alice do with the nonce?
  - That is, how to compute the response?
- How can Bob verify the response?
- Should we rely on passwords or keys?

CHALLENGE-RESPONSE



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

GENERIC CHALLENGE-RESPONSE



- In practice, how to achieve this?
- Hashed pwd works
- Maybe crypto is better, Why?

Authentication: Symmetric Key

SYMMETRIC KEY NOTATION

- Encrypt plaintext P with key K

  $C = E(P,K)$

- Decrypt ciphertext C with key K

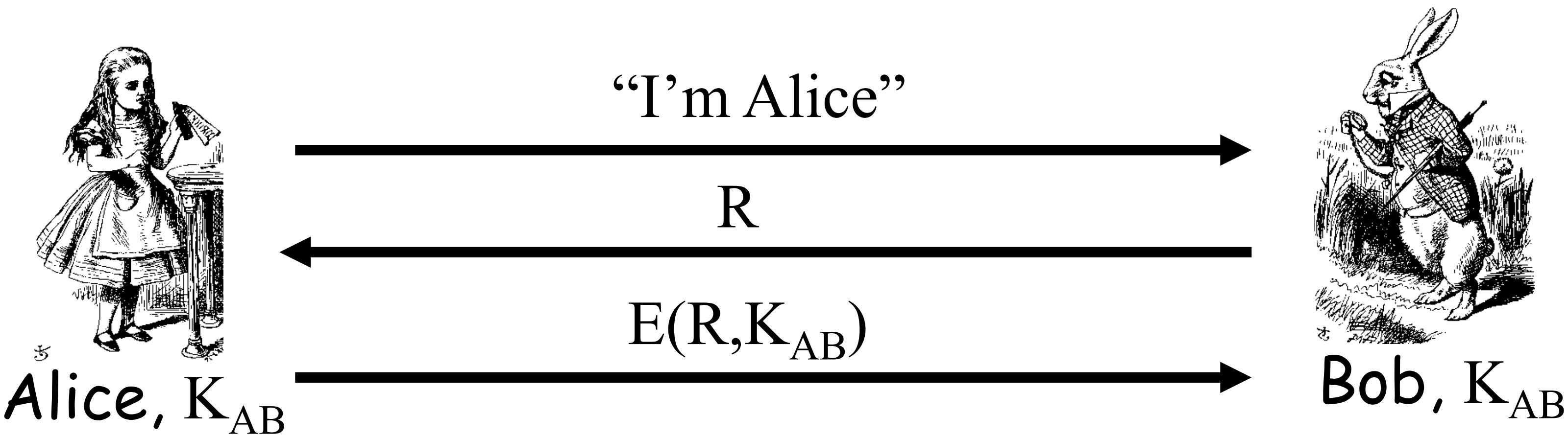
  $P = D(C,K)$

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

AUTHENTICATION: SYMMETRIC KEY

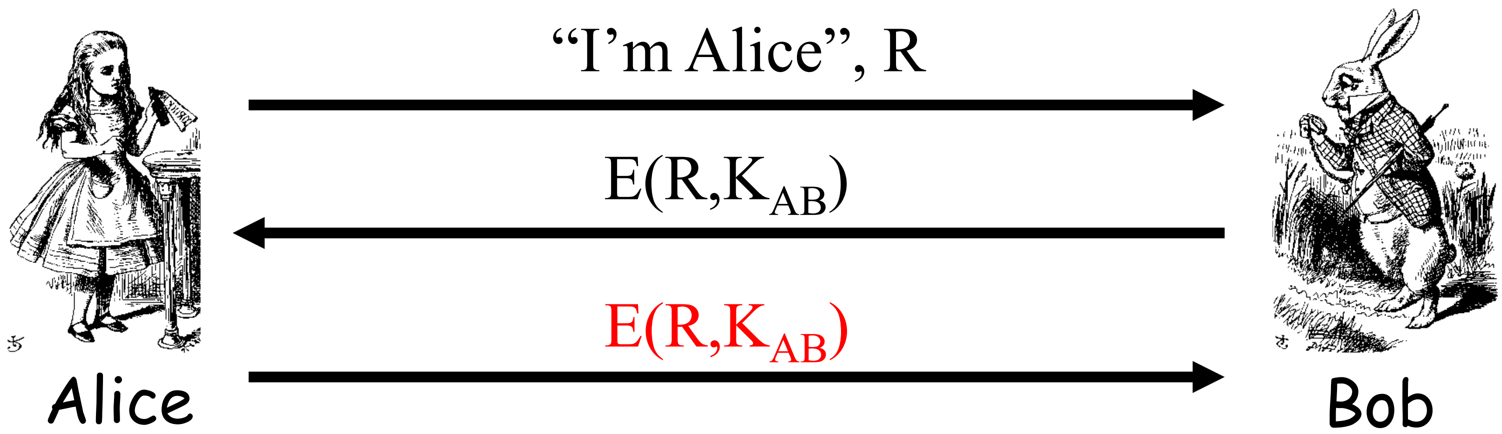
- Alice and Bob share symmetric key K_{AB}
- Key K_{AB} known only to Alice and Bob
- Authenticate by proving knowledge of shared symmetric key
- How to accomplish this with the following conditions?
  - Must not reveal key
  - Must not allow replay attack
  - Must be verifiable, …

AUTHENTICATION WITH SYM KEY



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

MUTUAL AUTHENTICATION?

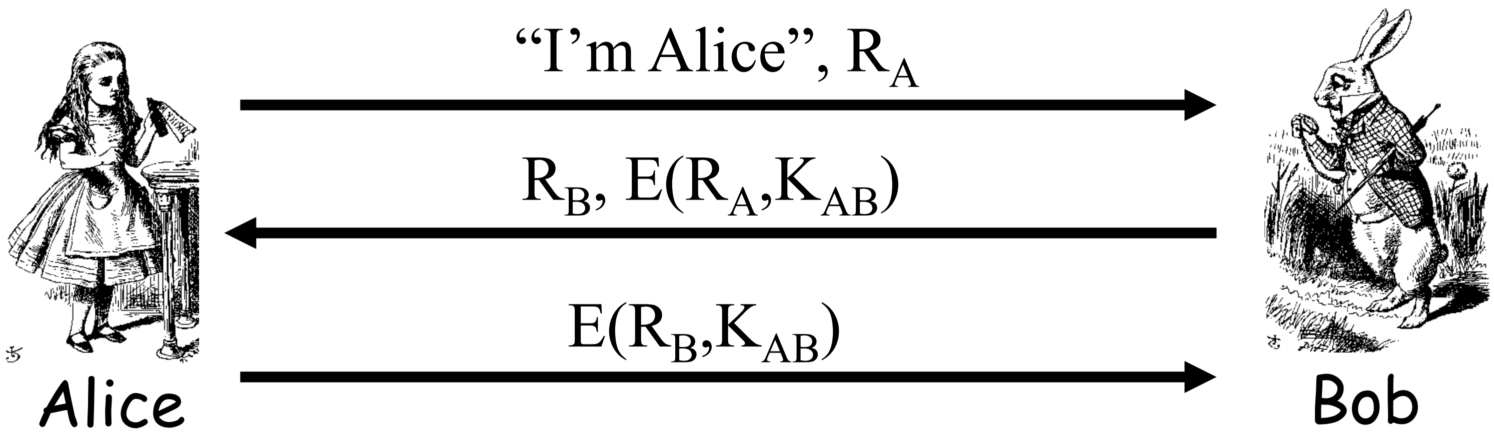


- What's wrong with this picture?
- "Alice" could be Trudy (or anybody else)!

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 to work…

MUTUAL AUTHENTICATION



- This provides mutual authentication
- Is it secure? See the next slide…

MUTUAL AUTHENTICATION ATTACK

Trudy

1. "I'm Alice", R_A →

2. R_B, $E(R_A,K_{AB})$ ←

5. $E(R_B,K_{AB})$ →

Bob

Trudy

3. "I'm Alice", R_B →

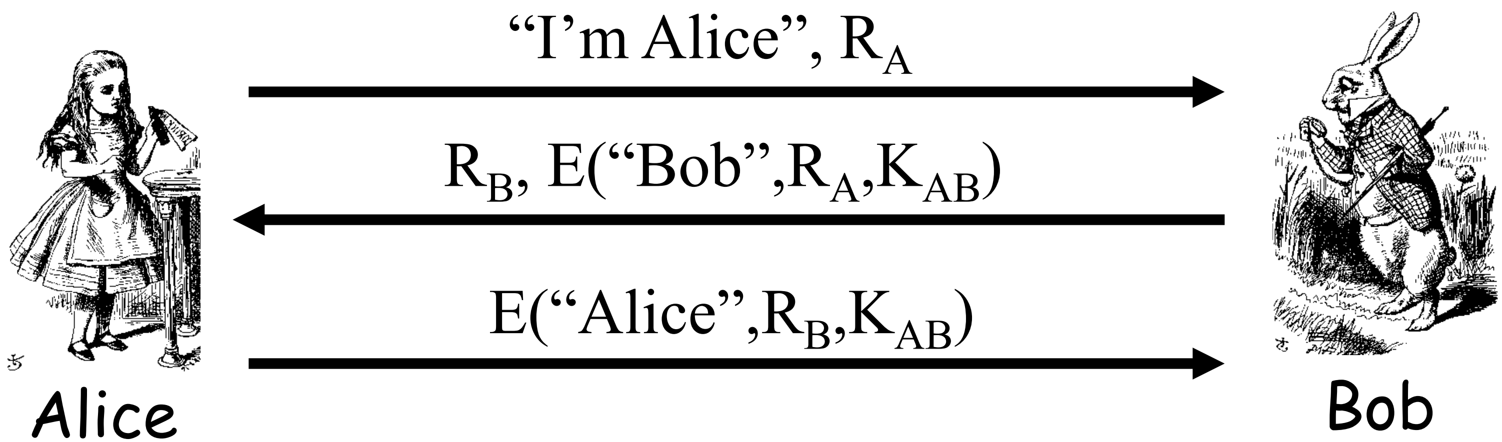
4. R_C, $E(R_B,K_{AB})$ ←

Bob

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

SYM KEY MUTUAL AUTHENTICATION



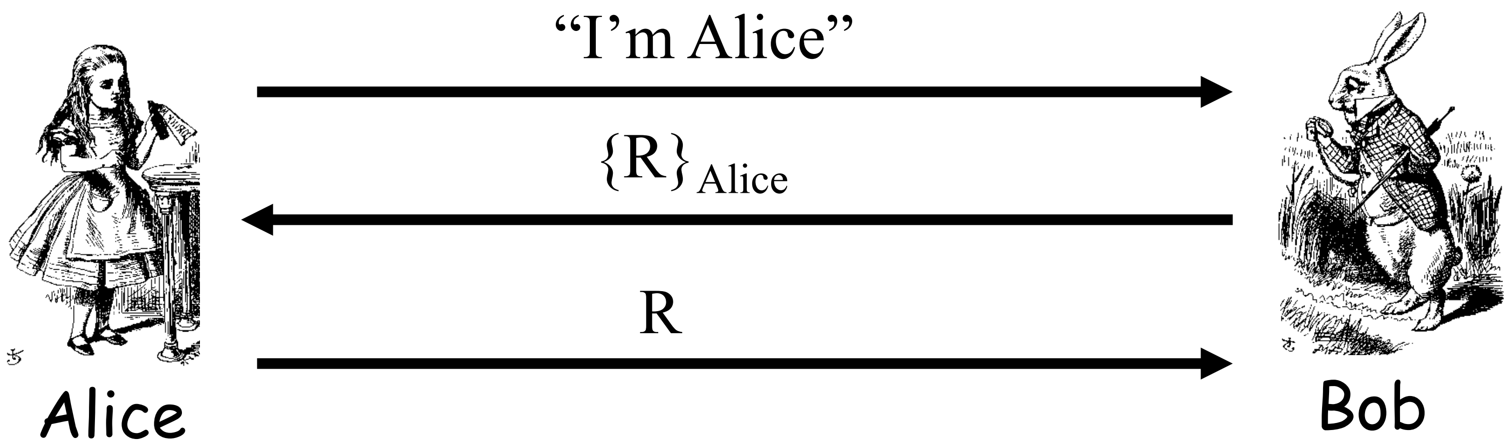
- Do these “insignificant” changes help?
- **Yes!**

Public Key Authentication

PUBLIC KEY NOTATION

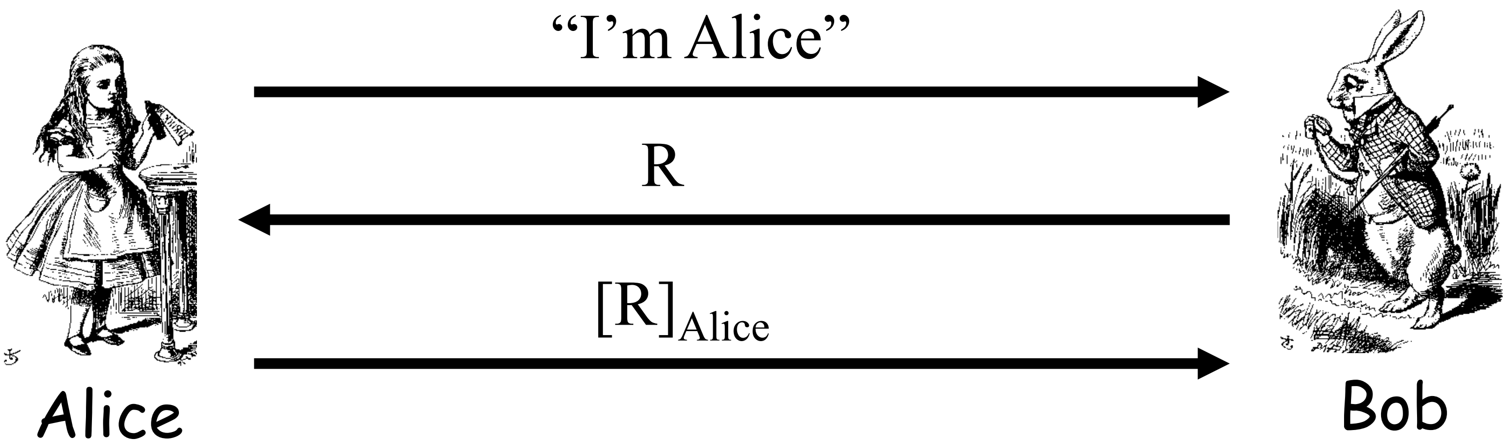
- Encrypt M with Alice's public key: $\{M\}_{\text{Alice}}$
- Sign M with Alice's private key: $[M]_{\text{Alice}}$
- Then
  - $[\{M\}_{\text{Alice}}]_{\text{Alice}} = M$
  - $\{[M]_{\text{Alice}}\}_{\text{Alice}} = M$
- **Anybody** can do **public key** operations
- Only **Alice** can use her **private key** (sign)

PUBLIC KEY AUTHENTICATION



- Is this secure?
- Trudy can get Alice to decrypt anything!
  - Should not use the key for encryption
  - Must have two key pairs

PUBLIC KEY AUTHENTICATION



- Is this secure?
- Trudy can get Alice to sign anything!
  - Should not use the key for sign
  - Must 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

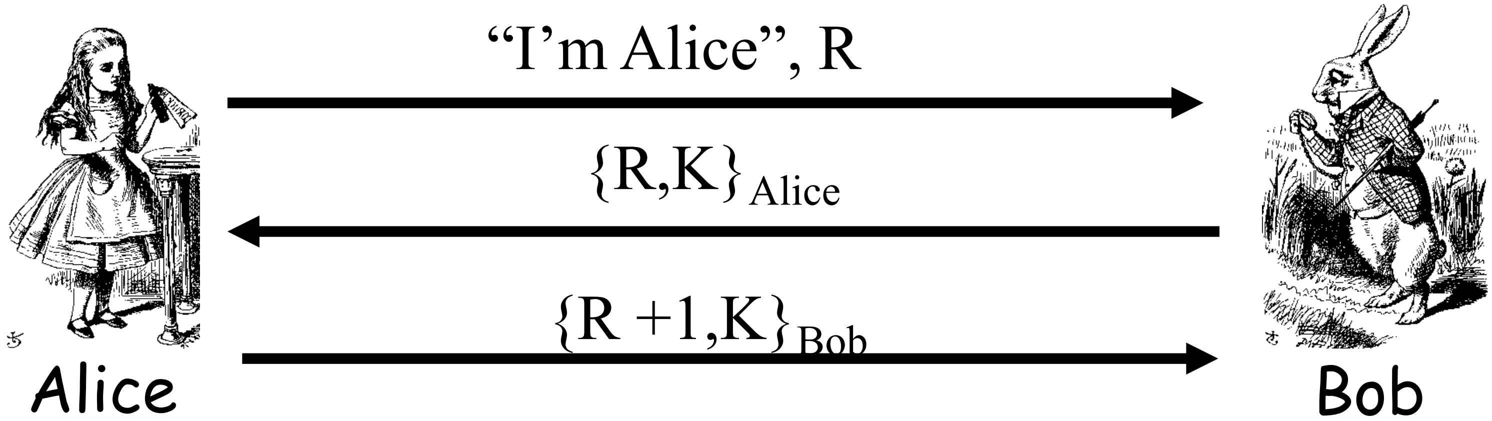
- Session key: temporary key, used for a short time period
- Usually, a session key is required
  - i.e. a symmetric key for a particular session
  - used for confidentiality and/or integrity
  - Limit damage if one session key compromised

SESSION KEY

- 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

PUB KEY AUTHEN AND SESS KEY

- **Using Encryptions of Alice and Bob**



- 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

- next

PUB KEY AUTHEN AND SESS KEY

- **Using Signs of Alice and Bob**

Alice

“I’m Alice”, R →

← $[R,K]_{Bob}$

$[R+1,K]_{Alice}$ →

Bob

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

PUB KEY AUTHEN AND SESS KEY

- **First Sign and encrypt**

Alice

$$\text{Alice} \xrightarrow{\text{“I'm Alice”}, R} \text{Bob}$$

$$\text{Alice} \xleftarrow{\{[R,K]_{Bob}\}_{Alice}} \text{Bob}$$

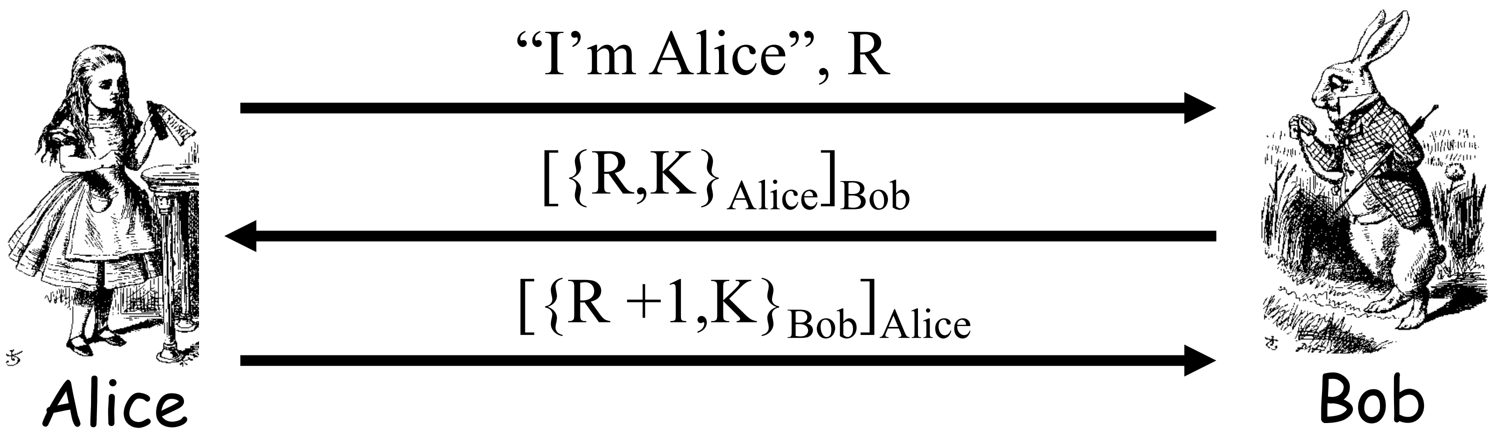
$$\text{Alice} \xrightarrow{\{[R+1,K]_{Alice}\}_{Bob}} \text{Bob}$$

Bob

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

PUB KEY AUTHEN AND SESS KEY

- **First encrypt and Sign**



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

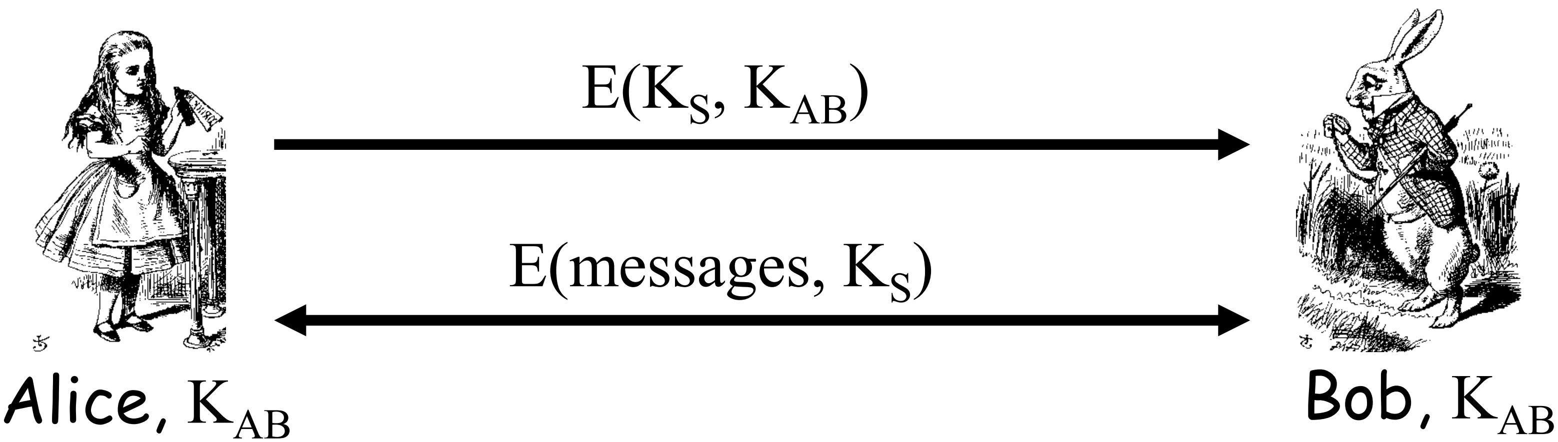
PERFECT FORWARD SECRECY

- 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

- Suppose Alice and Bob share key K_{AB}
- 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 ensures PFS?

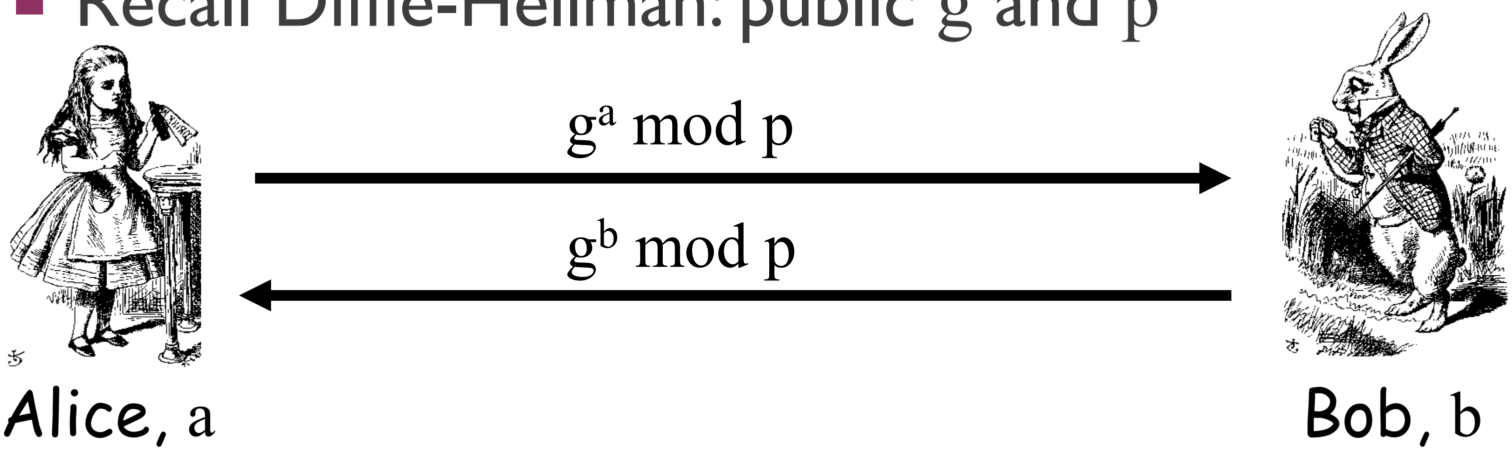
NAÏVE SESSION KEY PROTOCOL



- Trudy could also record $E(K_S, K_{AB})$
- If Trudy later gets K_{AB}, she can get K_S
  - Then Trudy can decrypt recorded messages

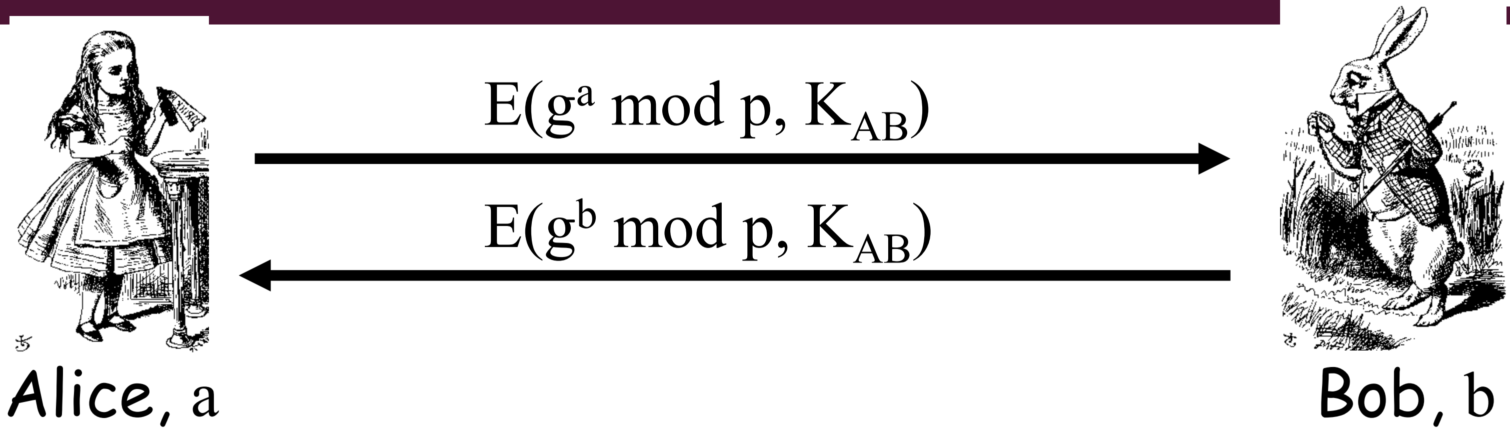
PERFECT FORWARD SECRECY

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



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

PERFECT FORWARD SECRECY



- Session key $K_S = g^{ab} \bmod p$
  - $g^a \cdot g^b = g^{a+b} \neq (g^a)^b = g^{a \cdot b}$
- Alice forgets a, Bob forgets b
- **So called Ephemeral Diffie-Hellman**
- Not even Alice and Bob can later recover K_S
- Other ways to do PFS?

MUTUAL AUTHEN, SESS KEY & PFS

"I'm Alice", R_A →

← R_B, $[\{R_A, g^b \bmod p\}_{Alice}]_{Bob}$

$[\{R_B, g^a \bmod p\}_{Bob}]_{Alice}$ →

Alice　　　　　　　　　　　　　　　　　　　　　　Bob

- 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 the current time
- Timestamps used in many security protocols (Kerberos, for example)
- Timestamps reduce number of messages
  - Like a nonce that both sides know in advance
- But, use of timestamps implies that time is a security-critical parameter
- Clocks never exactly the same, so must allow for clock skew — risk of replay
- How much clock skew is enough?

PUB KEY AUTHEN WITH TIMESTAMP T

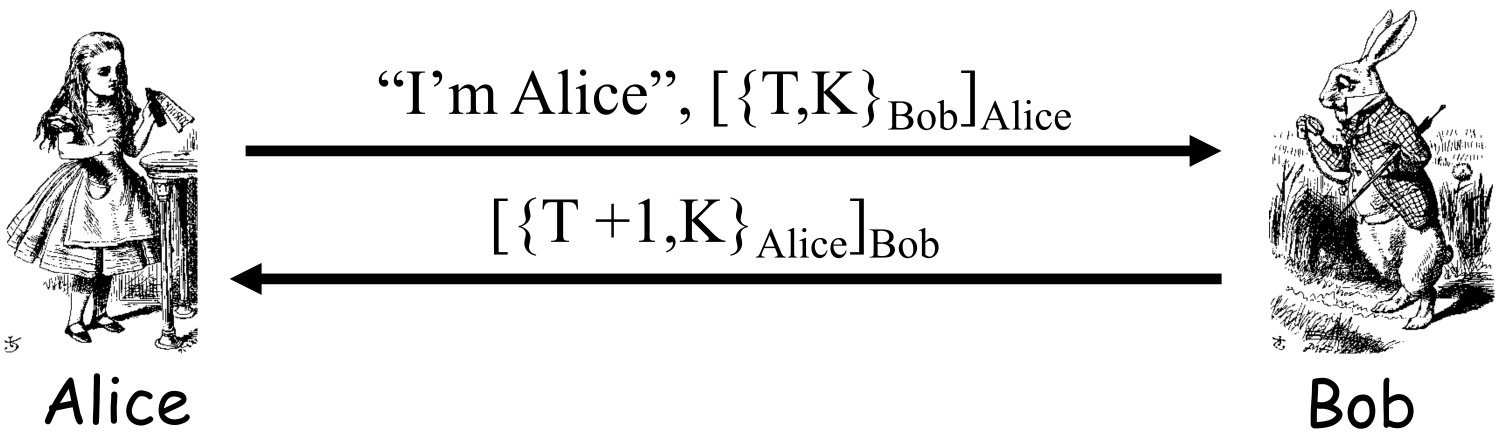
Alice

“I’m Alice”, $\{[T,K]_{Alice}\}_{Bob}$ →

← $\{[T+1,K]_{Bob}\}_{Alice}$

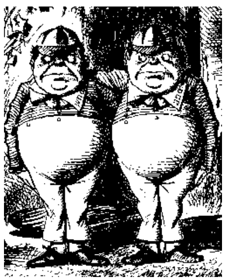
Bob

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



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

PUB KEY AUTHEN WITH TIMESTAMP T



Trudy

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

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

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!

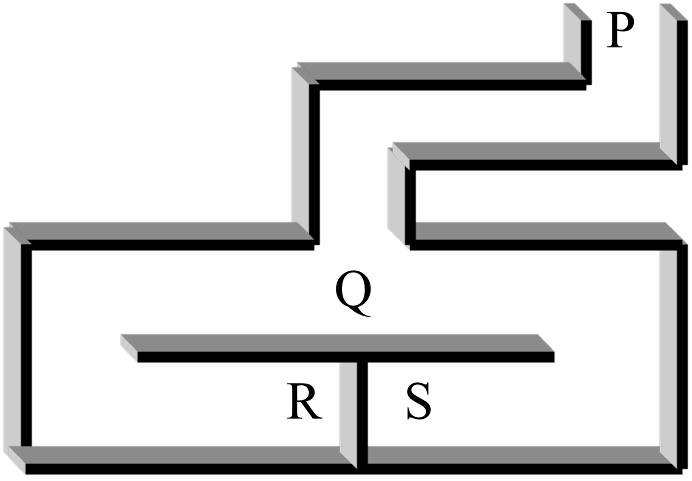
ZERO KNOWLEDGE PROOF (ZKP)

ZERO KNOWLEDGE PROOF (ZKP)

- Alice wants to prove that she knows a secret without revealing **any** info about it
- Bob must verify that Alice knows secret
  - Even though he gains no info about the secret
- Process is probabilistic
  - Bob can verify that Alice knows the secret to an arbitrarily high probability
- An "interactive proof system"

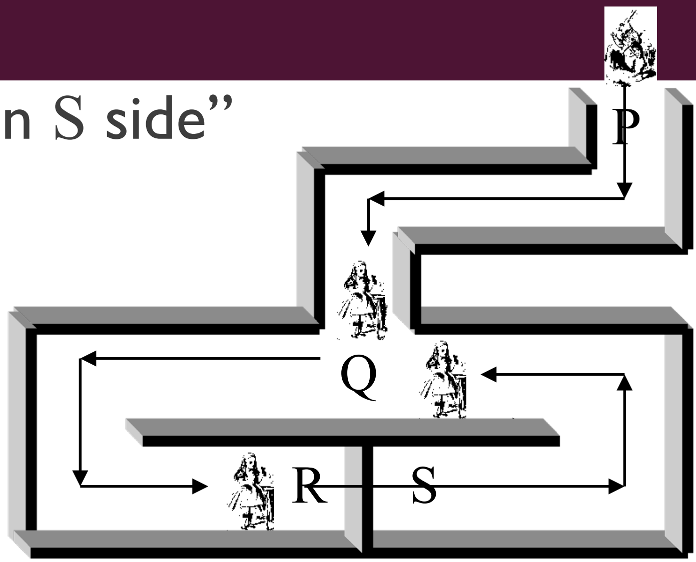
BOB'S CAVE

- Alice claims to know secret phrase to open path between R and S ("open sasparilla")
- Can she convince Bob that she knows the secret without revealing phrase?



BOB'S CAVE

- Bob: "Alice come out on S side"



- Alice (quietly): "Open sasparilla"
- Apse Alice does not know secret

- Without knowing secret, Alice could come out from the correct side with probability ½
- If Bob repeats this n times, then Alice can only fool Bob with probability $1/2^n$

FIAT-SHAMIR PROTOCOL

- Cave-based protocols are inconvenient
  - Can we achieve same effect without a cave?
- It is known that finding square roots modulo N is difficult (like factoring)
- Suppose $N = pq$, where p and q prime
- Alice has a **secret** S
  - N and $v = S^2 \bmod N$ are public, S is secret
- Alice must convince Bob that she knows S without revealing any information about S

FIAT-SHAMIR PROTOCOL

- N and $v = S^2 \bmod N$ are public, S is secret
- Example
  - P = 7, q = 5, N = 35
  - S=10, S^2 =100
  - 100 mod 35 = 30 mod 35
  - 35 and 30: public, 10: secret

$$\sqrt{30 \bmod 35} = ???$$

FIAT-SHAMIR

secret S
random r

$x = r^2 \bmod N$ →

← $e \in \{0,1\}$

$y = r * S^e \bmod N$ →

Alice

Bob

- **Public:** Modulus N and $v = S^2 \bmod N$
- Alice selects random r
- Bob chooses $e \in \{0,1\}$
- Bob verifies that $y^2 = x * v^e \bmod N$
  - Why? Because… $y^2 = r^2 \cdot S^{2e} = r^2 \cdot (S^2)^e = x \cdot v^e \bmod N$

FIAT-SHAMIR: E = 1

Secret S
Random r

$x = r^2 \bmod N$ →

← $e = 1$

$y = r*S \bmod N$ →

Alice

Bob
Random e

- **Public:** Modulus N and $v = S^2 \bmod N$
- Alice selects random r, Bob chooses $e = 1$
- If $y^2 = x \cdot v \bmod N$ then Bob accepts it
  - I.e., "Alice" passes this iteration of the protocol
- Note that Alice must know S in this case

FIAT-SHAMIR: E = 0

Alice

Secret S
Random r

$x = r^2 \bmod N$ →

$e = 0$ ←

$y = r \bmod N$ →

Bob

Random e

- **Public:** Modulus N and $v = S^2 \bmod N$
- Alice selects random r, Bob chooses $e = 0$
- Bob must verify that $y^2 = x \bmod N$
- Alice does **not** need to know S in this case!

FIAT-SHAMIR

- **Public:** modulus N and $v = S^2 \bmod N$
- **Secret:** Alice knows S
- Alice selects random r and **commits** to r by sending $x = r^2 \bmod N$ to Bob
- Bob sends **challenge** $e \in \{0,1\}$ to Alice
- Alice **responds** with $y = r * S^e \bmod N$
- Bob checks that $y^2 = x * v^e \bmod N$
  - **Does this prove response is from Alice?**

DOES FIAT-SHAMIR WORK?

- If everyone follows protocol, math works:
  - Public: $v = S^2 \bmod N$
  - Alice to Bob: $x = r^2 \bmod N$ and $y = r \cdot S^e \bmod N$
  - Bob verifies: $y^2 = x \cdot v^e \bmod N$
- Can Trudy convince Bob she is Alice?
  - If Trudy expects $e = 0$, she can send $x = r^2$ in msg 1 and $y = r$ in msg 3 (i.e., follow protocol)
  - If Trudy expects $e = 1$, she can send $x = r^2 * v^{-1}$ in msg 1 and $y = r$ in msg 3
- If Bob chooses $e \in \{0,1\}$ at random, Trudy can only trick Bob with probability $1/2$

FIAT-SHAMIR FACTS

- Trudy can trick Bob with prob $1/2$, but…
  - …after n iterations, the probability that Trudy can convince Bob that she is Alice is only $1/2^n$
  - Just like Bob's cave!
- Bob's $e \in \{0,1\}$ must be unpredictable
- Alice must use new r each iteration or else
  - If $e = 0$, Alice sends r in message 3
  - If $e = 1$, Alice sends $r*S$ in message 3
  - Anyone can find S given **both** r and $r*S$

FIAT-SHAMIR ZERO KNOWLEDGE?

- Zero knowledge means that nobody learns **anything** about the secret S
  - **Public:** $v = S^2 \bmod N$
  - Trudy sees $r^2 \bmod N$ in message 1
  - Trudy sees $r*S \bmod N$ in message 3 (if $e = 1$)
- If Trudy can find r from $r^2 \bmod N$, gets S
  - But that requires modular square root
  - If Trudy could find modular square roots, she can get S from **public** v
- The protocol does not "help" to find S

ZKP IN THE REAL WORLD

- Public keys identify users
  - No anonymity if public keys transmitted
- ZKP offers a way to authenticate without revealing identities
- ZKP supported in Microsoft's Next Generation Secure Computing Base (NGSCB)
  - ZKP used to authenticate software "without revealing machine identifying data"
  - ZKP **not** just fun and games for mathematicians!

BEST AUTHENTICATION PROTOCOL?

- It depends on…
  - The sensitivity of the application/data
  - The delay that is tolerable
  - The cost (computation) that is tolerable
  - What crypto is supported
    - Public key, symmetric key, hash functions
  - Whether mutual authentication is required
  - Whether PFS, anonymity etc. area concern
- …and possibly other factors