CSE 484 (Winter 2010)

Asymmetric Cryptography

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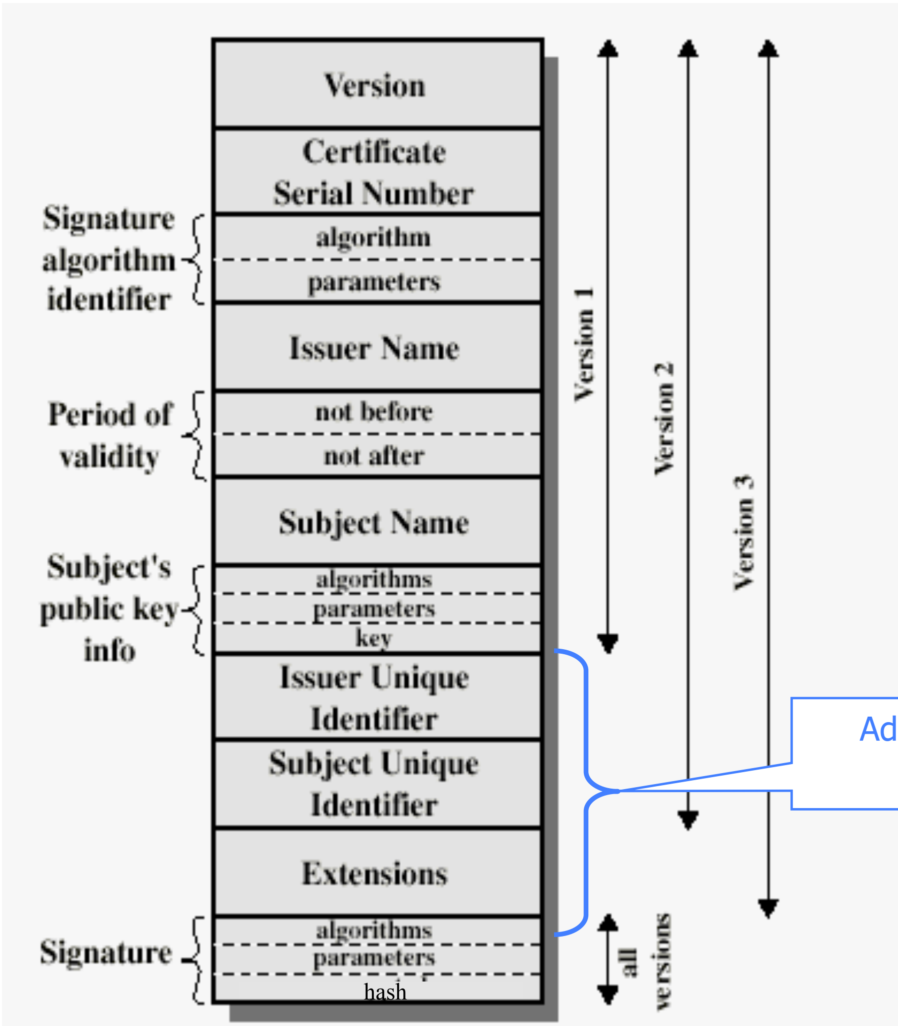
Goals for Today

- PKI
- Key Establishment

X.509 Authentication Service

- Internet standard (1988 onward)
- Specifies certificate format
  - X.509 certificates are used in IPSec and SSL/TLS
- Specifies certificate directory service
  - For retrieving other users' CA-certified public keys
- Specifies a set of authentication protocols
  - For proving identity using public-key signatures
- Does <u>not</u> specify crypto algorithms
  - Can use it with any digital signature scheme and hash function, but hashing is required before signing

X.509 Certificate



Added in X.509 versions 2 and 3 to address usability and security problems

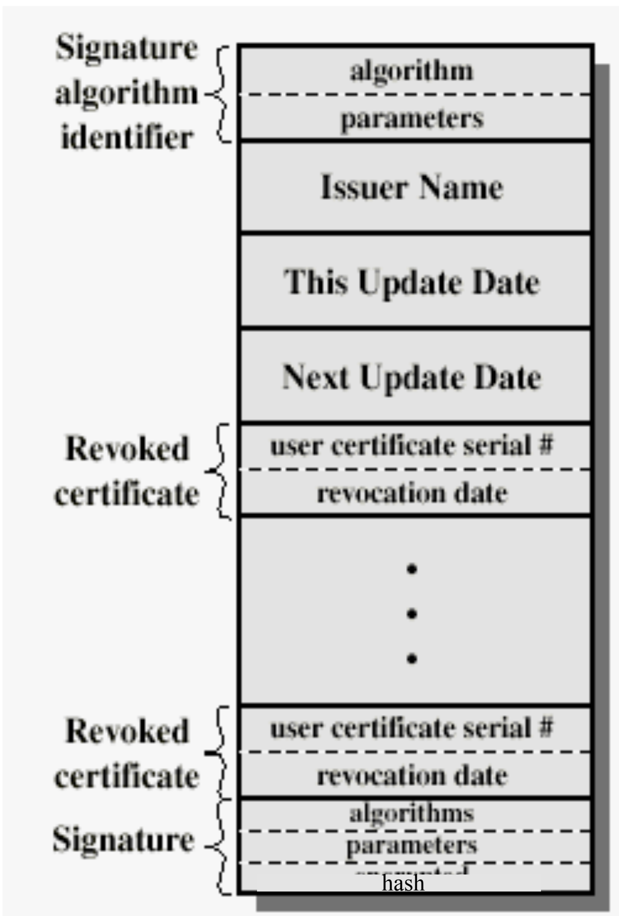
Certificate Revocation

- Revocation is <u>very</u> important
- Many valid reasons to revoke a certificate
  - Private key corresponding to the certified public key has been compromised
  - User stopped paying his certification fee to this CA and CA no longer wishes to certify him
  - CA's private key has been compromised!
- Expiration is a form of revocation, too
  - Many deployed systems don't bother with revocation
  - Re-issuance of certificates is a big revenue source for certificate authorities

Certificate Revocation Mechanisms

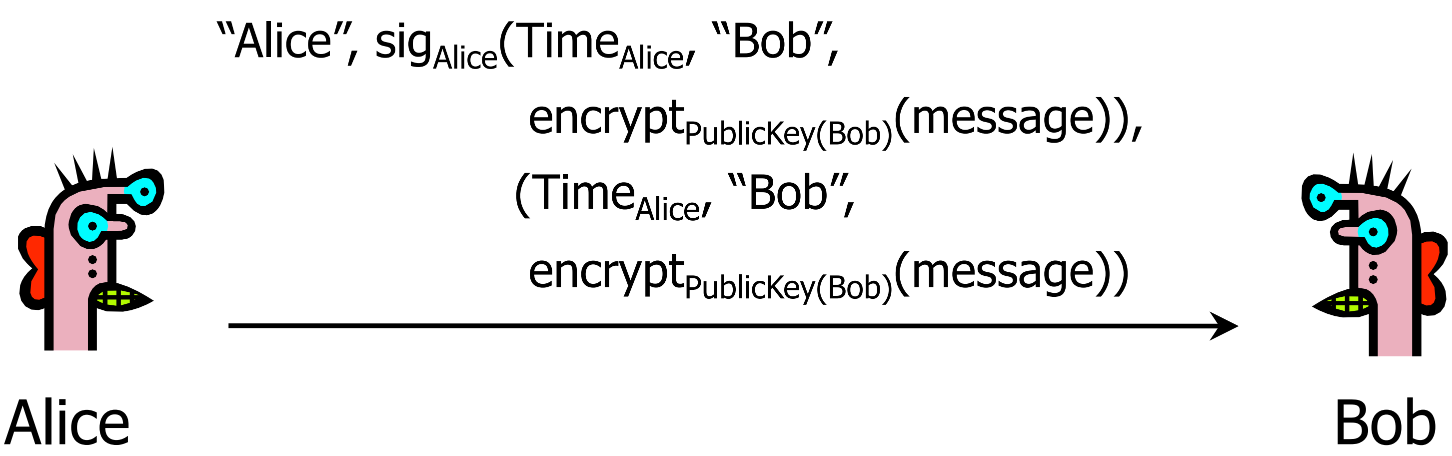
- Online revocation service
  - When a certificate is presented, recipient goes to a special online service to verify whether it is still valid
    - Like a merchant dialing up the credit card processor
- Certificate revocation list (CRL)
  - CA periodically issues a signed list of revoked certificates
    - Credit card companies used to issue thick books of canceled credit card numbers
  - Can issue a "delta CRL" containing only updates

X.509 Certificate Revocation List



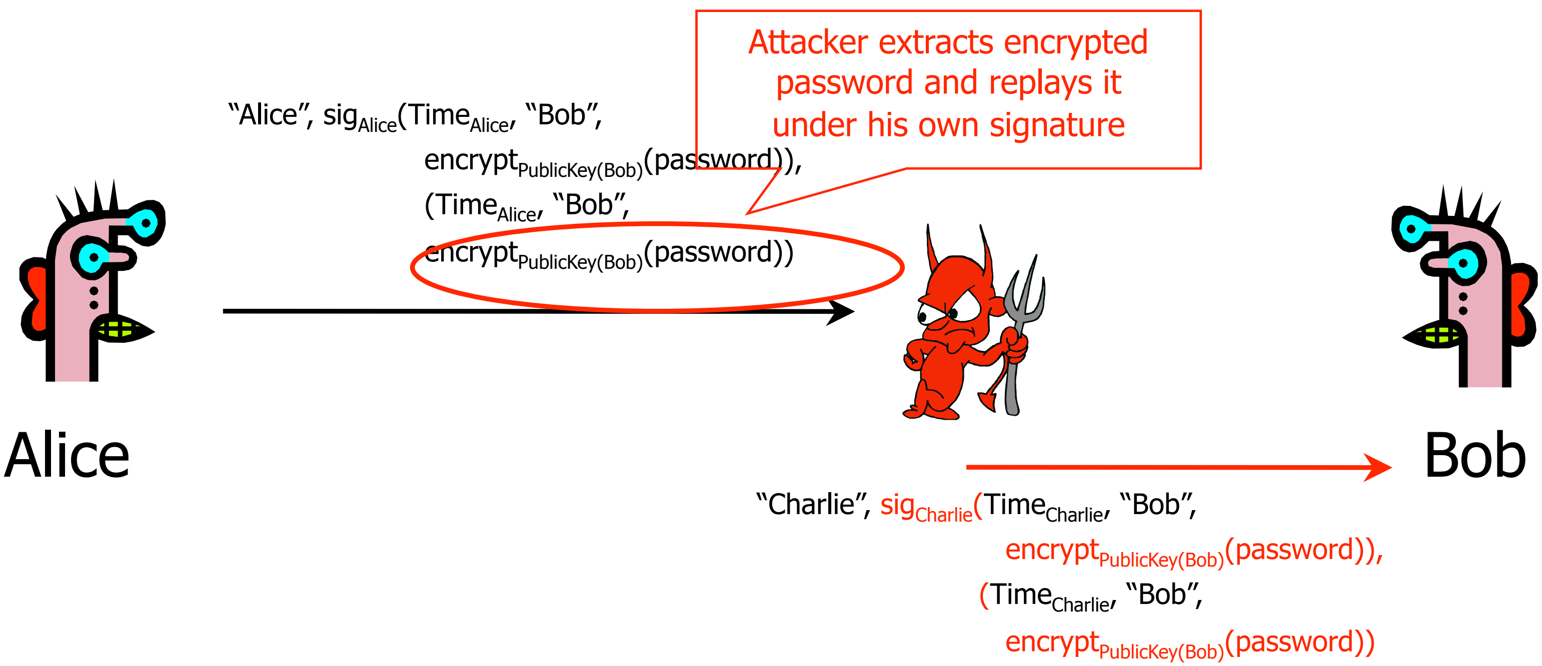
Because certificate serial numbers must be unique within each CA, this is enough to identify the certificate

X.509 Version 1



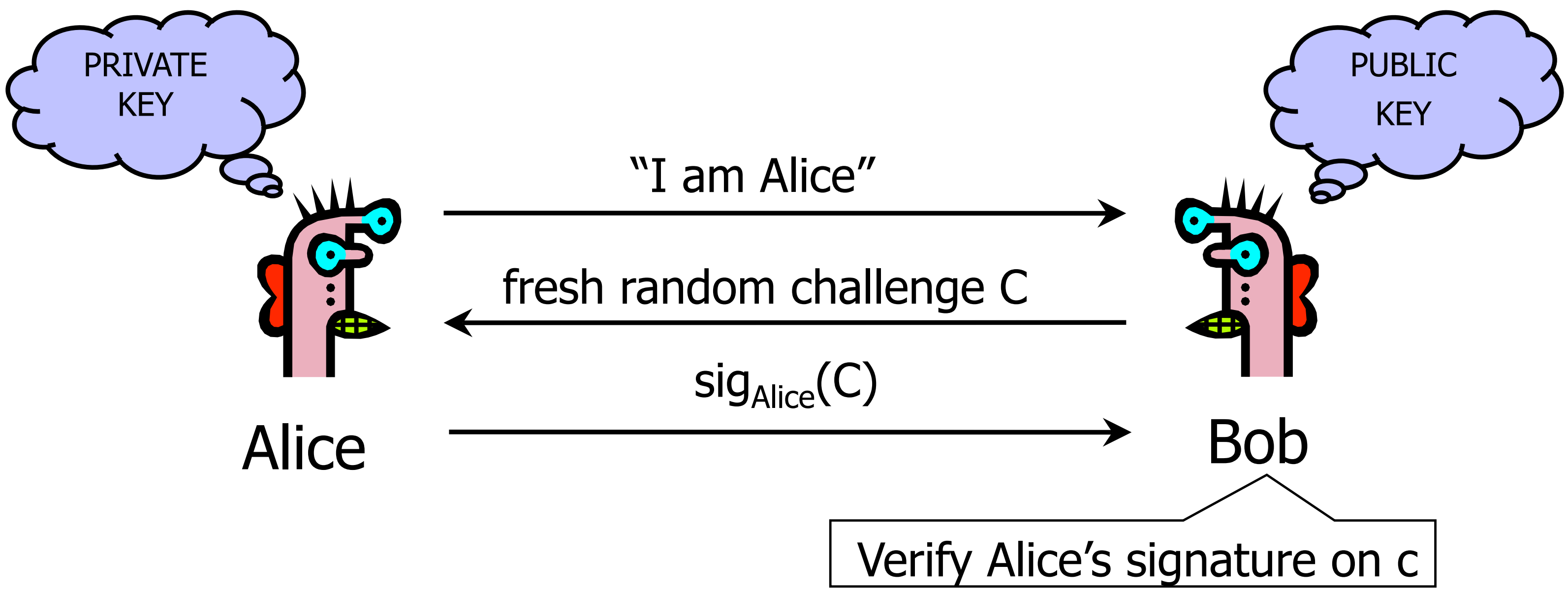
- Encrypt, then sign
  - Goal: achieve both confidentiality and authentication
  - E.g., encrypted, signed password for access control (for next slide: assume one password for whole system)
- Does this work?

Attack on X.509 Version 1



- Receiving encrypted password under signature does <u>not</u> mean that the sender actually knows the password!

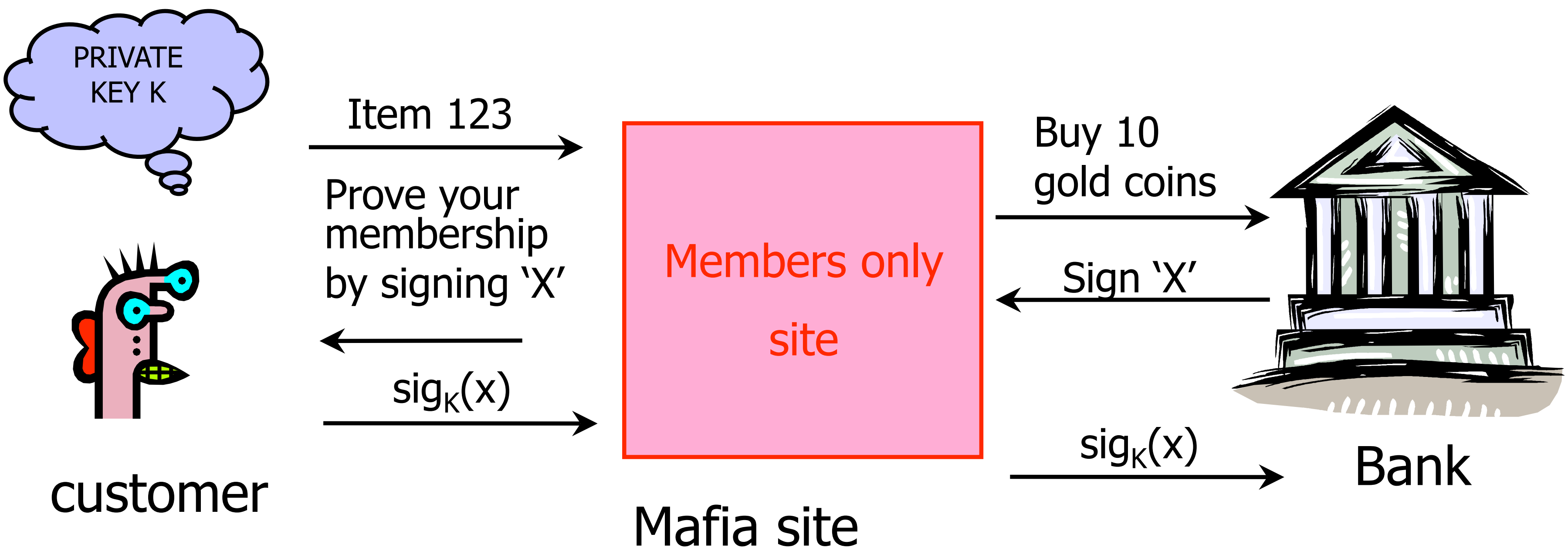
Authentication with Public Keys



1. Only Alice can create a valid signature
2. Signature is on a fresh, unpredictable challenge

Potential problem: Alice will sign anything

Mafia-in-the-Middle Attack [from Anderson's book]



One key recommendation: Don't use same public key / secret key pair for multiple applications. (Or make sure messages have different formats across applications.)

Secure Sessions

- Secure sessions are among the most important applications in network security
  - Enable us to talk securely on an insecure network
- Goal: secure bi-directional communication channel between two parties
  - The channel must provide confidentiality
    - Third party cannot read messages on the channel
  - The channel must provide authentication
    - Each party must be sure who the other party is
  - Other desirable properties: integrity, protection against denial of service, anonymity against eavesdroppers

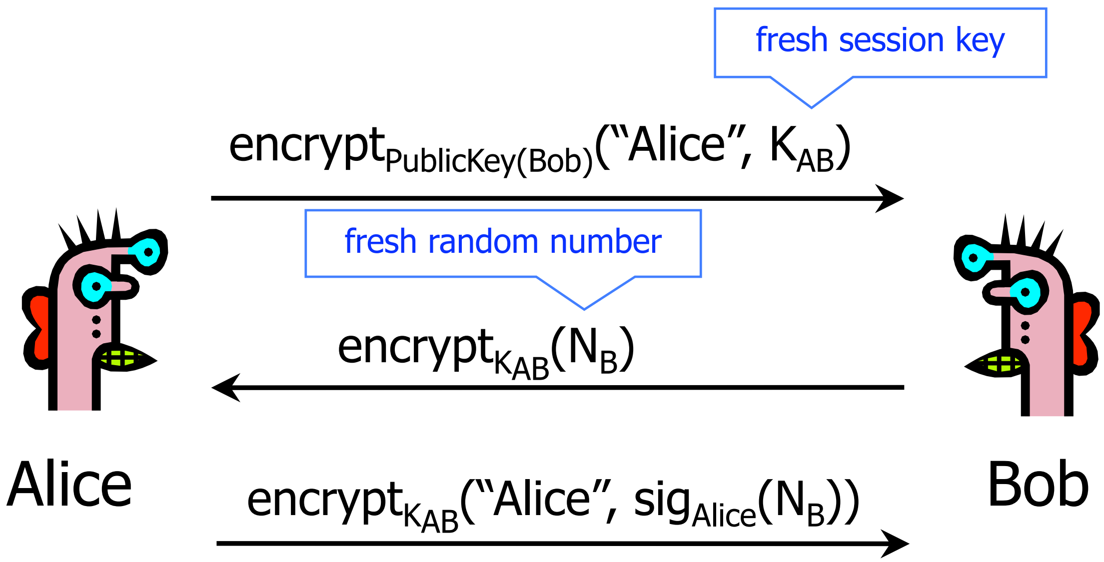
Key Establishment Protocols

- Common implementation of secure sessions:
  - Establish a secret key known only to two parties
  - Then use block ciphers for confidentiality, HMAC for authentication, and so on
- Challenge: how to establish a secret key
  - Using only <u>public</u> information?
  - Even if the two parties share a long-term secret, a fresh key should be created for each session
    - Long-term secrets are valuable; want to use them as sparingly as possible to limit exposure and the damage if the key is compromised
    - (Background: For N parties, there are N choose 2 = N*(N-1)/2 pairs of parties.)

Key Establishment Techniques

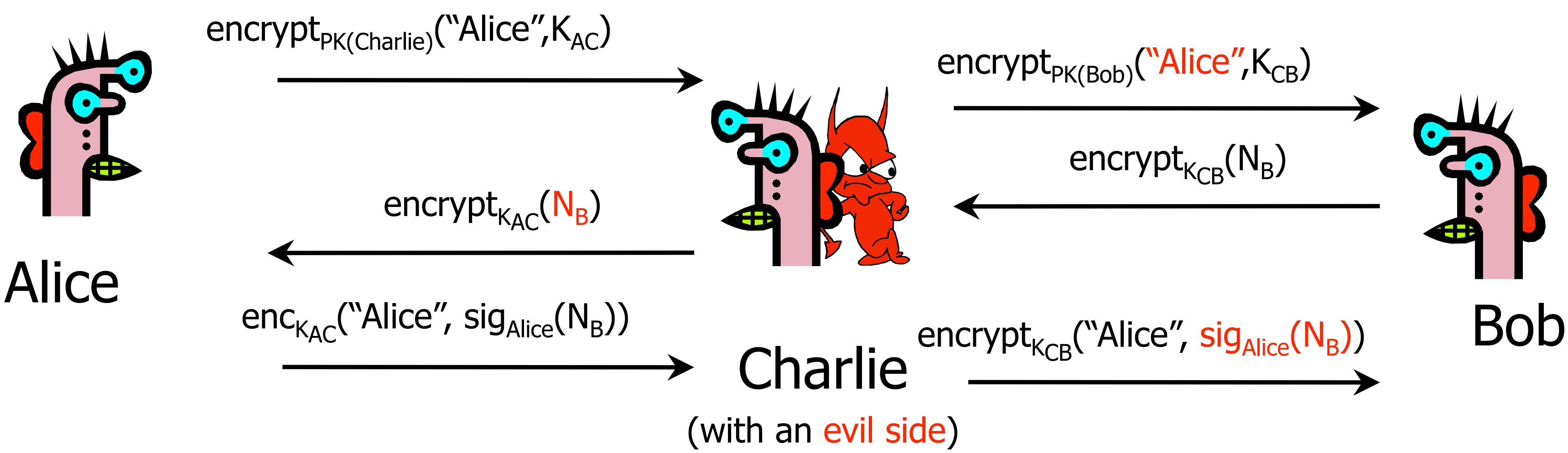
- Use a trusted key distribution center (KDC)
  - Every party shares a pairwise secret key with KDC
  - KDC creates a new random session key and then distributes it, encrypted under the pairwise keys
    - Example: Kerberos
- Use public-key cryptography
  - Diffie-Hellman authenticated with signatures
    - Example: IKE (Internet Key Exchange)
  - One party creates a random key, sends it encrypted under the other party's public key
    - Example: TLS (Transport Layer Security)

Early Version of SSL (Simplified)



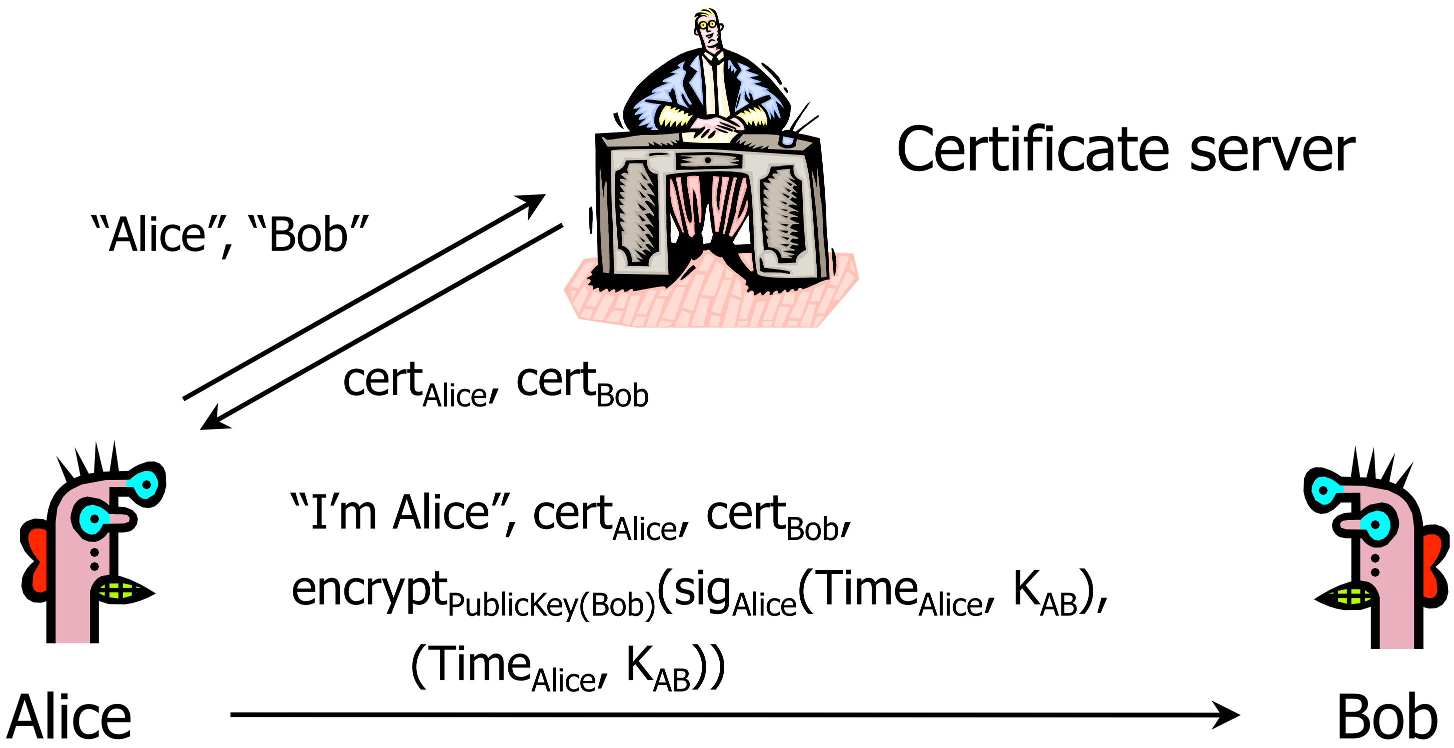
- Bob's reasoning: I must be talking to Alice because…
  - Whoever signed N_B knows Alice's private key… Only Alice knows her private key… Alice must have signed N_B… N_B is fresh and random and I sent it encrypted under K_{AB}… Alice could have learned N_B only if she knows K_{AB}… She must be the person who sent me K_{AB} in the first message...

Breaking Early SSL



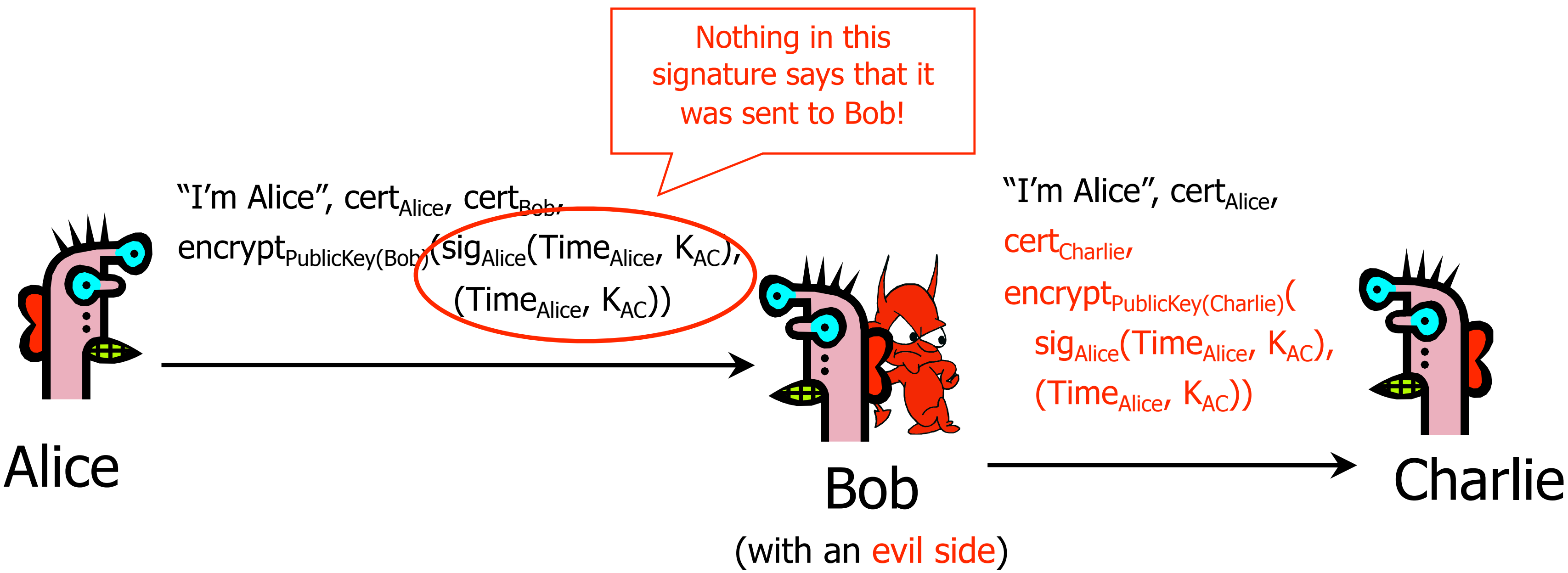
- Charlie uses his legitimate conversation with Alice to impersonate Alice to Bob
  - Information signed by Alice is not sufficiently explicit

Denning-Sacco Protocol



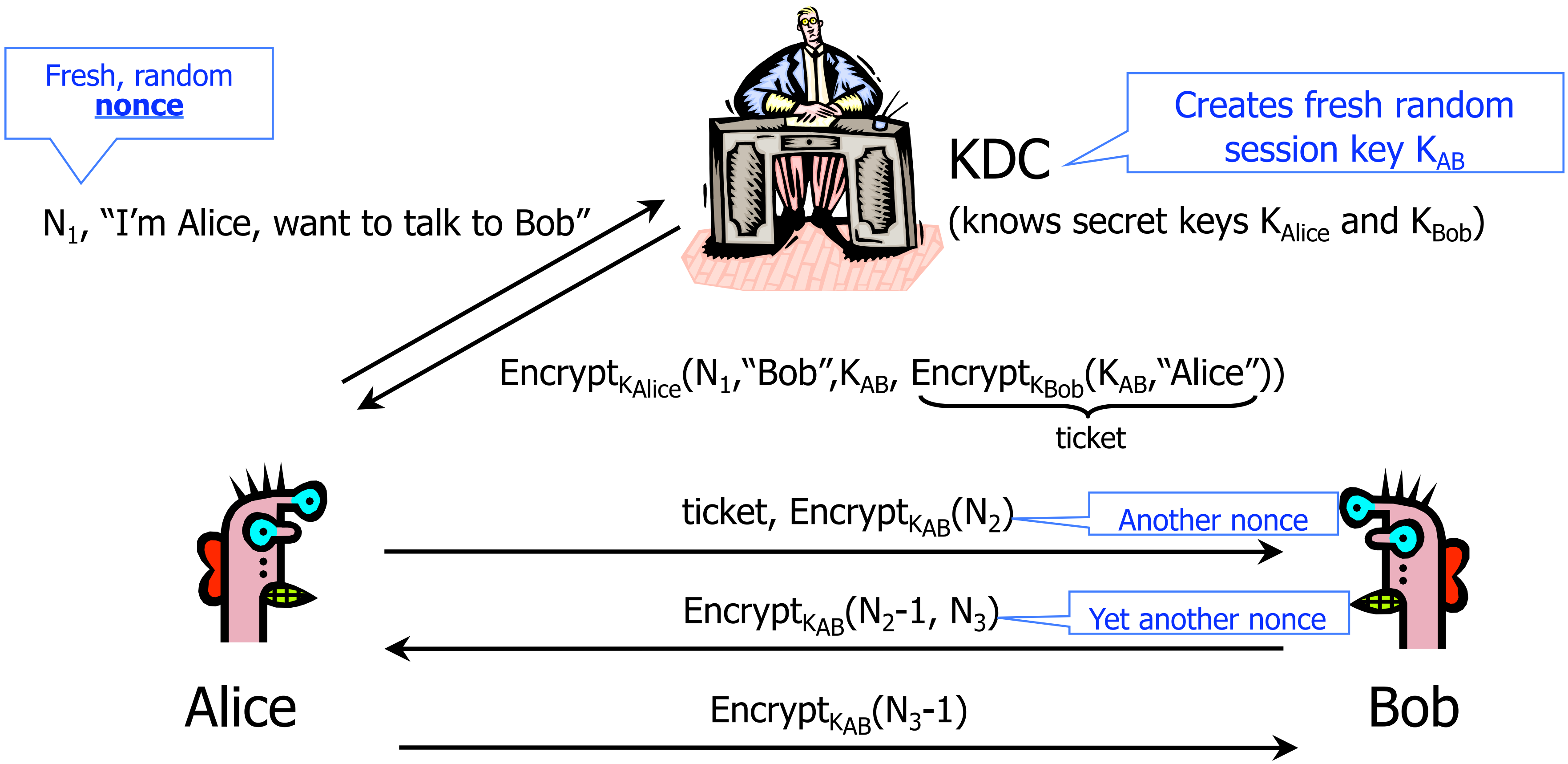
- Goal: establish a new shared key K_{AB} with the help of a trusted certificate service

Attack on Denning-Sacco



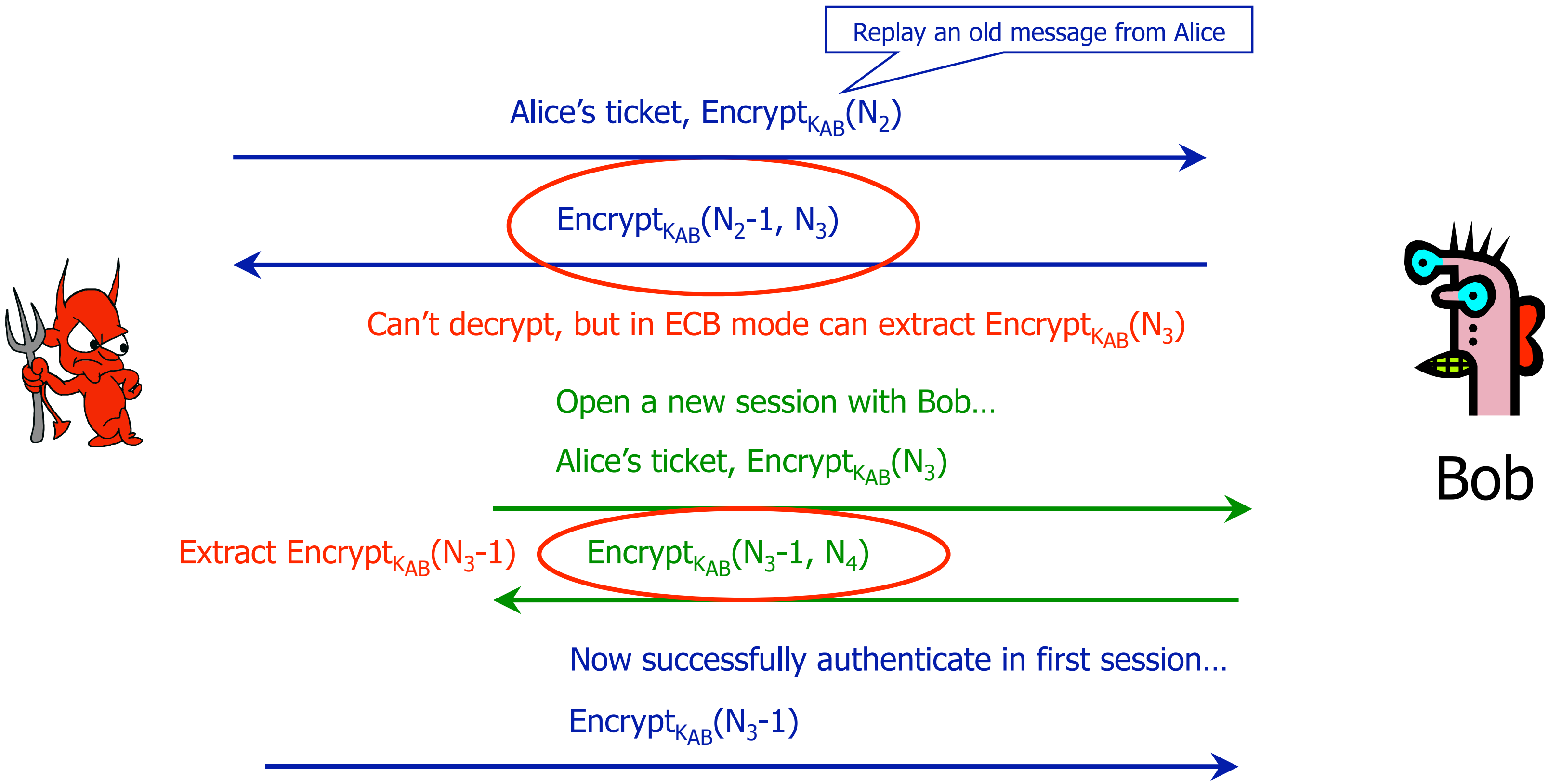
- Alice's signature is insufficiently explicit
  - Does not say to whom and why it was sent
- Alice's signature can be used to impersonate her

Private-Key Needham-Schroeder

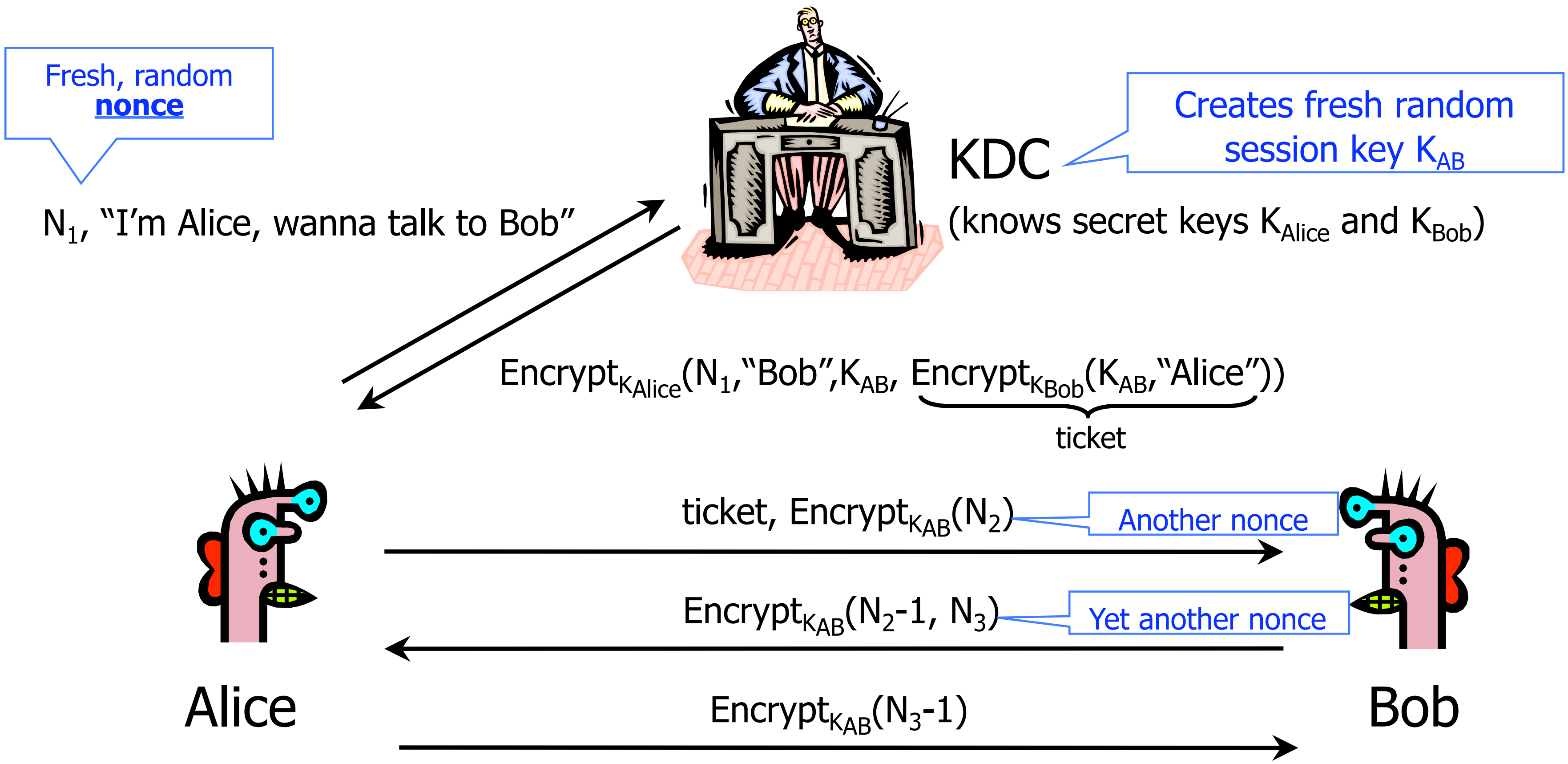


Reflection Attack

- Suppose symmetric encryption is in ECB/CBC mode…
  - (Easier to see with ECB mode, so assume that)



Private-Key Needham-Schroeder



- Another issue: If learn K_{AB} after session completes, then can re-use. (Solution: timestamps, nonces.)

Public-Key Needham-Schroeder

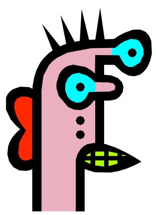
Alice's nonce

$\text{Encrypt}_{\text{PublicKey(Bob)}}(\text{“Alice”}, N_A)$ →

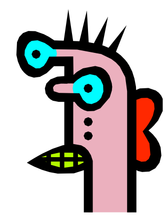
Bob's nonce

← $\text{Encrypt}_{\text{PublicKey(Alice)}}(N_A, N_B)$

$\text{Encrypt}_{\text{PublicKey(Bob)}}(N_B)$ →



Alice



Bob

Create new key from N_A and N_B, e.g., $N_A \oplus N_B$

Alice's reasoning:

- The only person who could know N_A is the person who decrypted 1st message
- Only Bob can decrypt message encrypted with Bob's public key
- Therefore, Bob is on the other end of the line

Bob is authenticated!

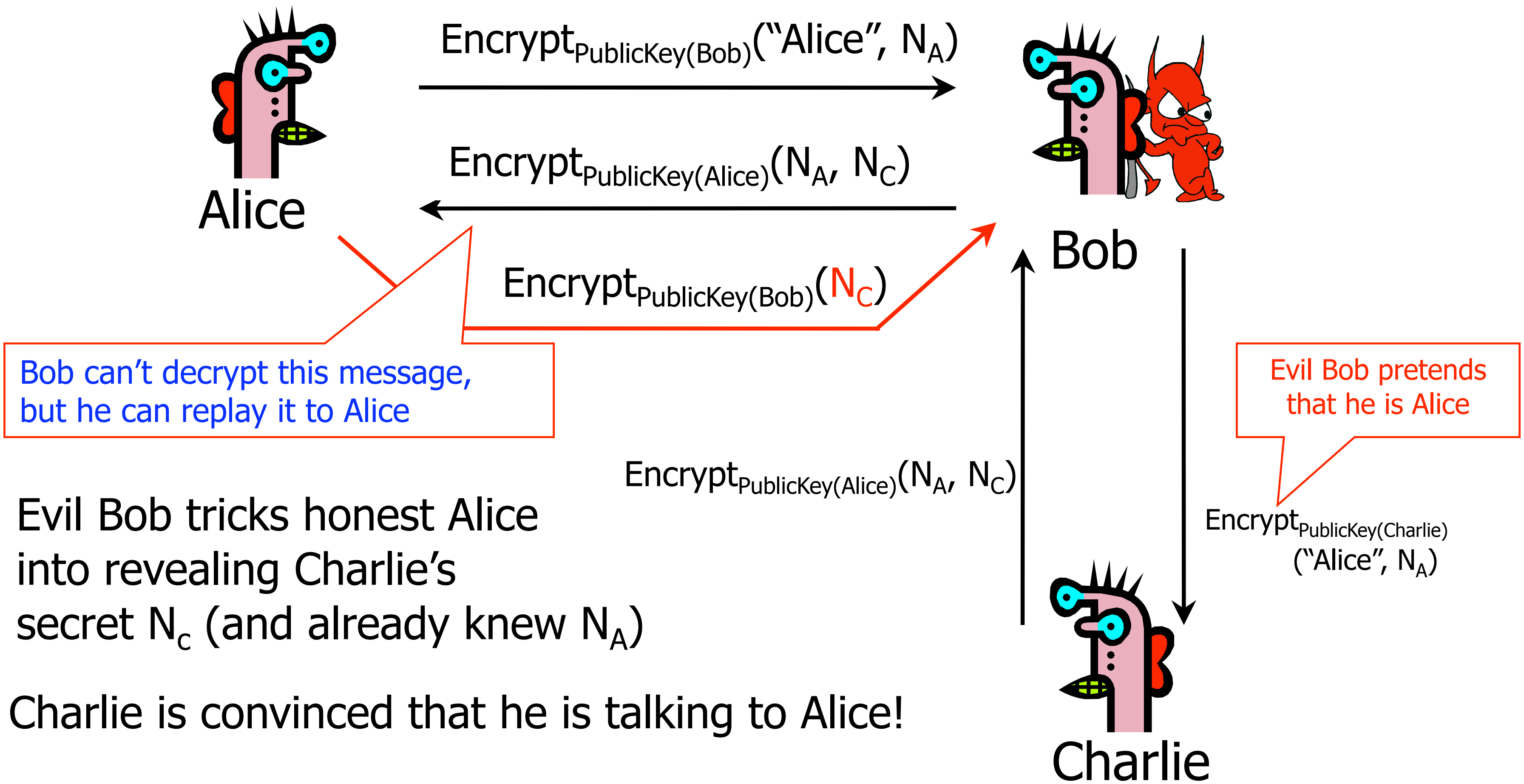
Bob's reasoning:

- The only way to learn N_B is to decrypt 2nd message
- Only Alice can decrypt 2nd message
- Therefore, Alice is on the other end

Alice is authenticated!

Attack on Needham-Schroeder

[published by Gavin Lowe]



Evil Bob tricks honest Alice into revealing Charlie's secret N_c (and already knew N_A)

Charlie is convinced that he is talking to Alice!

Lessons of Needham-Schroeder

- This is yet another example of design challenges
  - Alice is correct that Bob must have decrypted $\text{Encrypt}_{\text{PublicKey(Bob)}}(\text{“Alice”}, N_A)$, but this does not mean that $\text{Encrypt}_{\text{PublicKey(Alice)}}(N_A, N_B)$ came from Bob
- It is important to realize limitations of protocols
  - The attack requires that Alice willingly talk to attacker
    - Attacker uses a legitimate conversation with Alice to impersonate Alice to Charlie