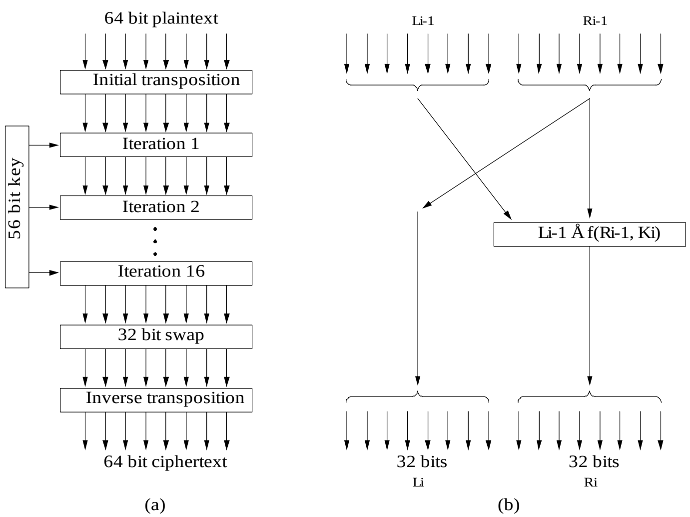
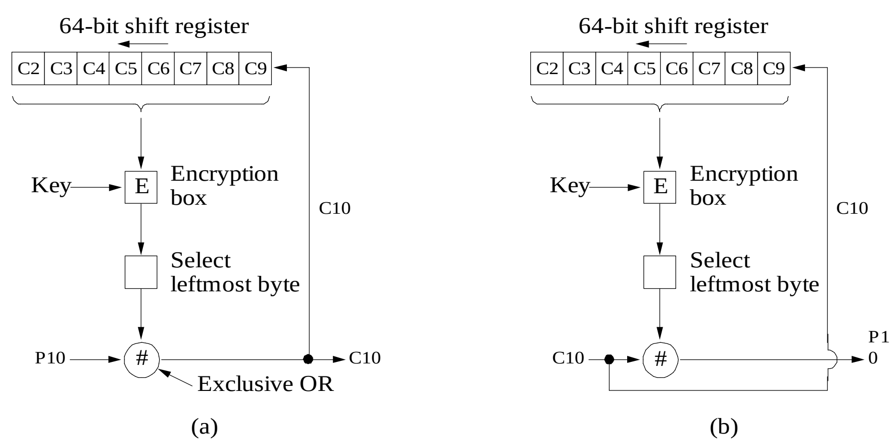
Announcements

- Project #4 Due this week
- Midterm #2 is Tuesday
- No Office hours next week

DES

- Block cipher: uses 56 bit keys, 64 bits of data
- Uses 16 stages of substitution
- Variations
  - cipher block chaining: xor output of block n with into block n+1
  - cipher feedback mode: use 64bit shift register
    - can produce one byte at a time





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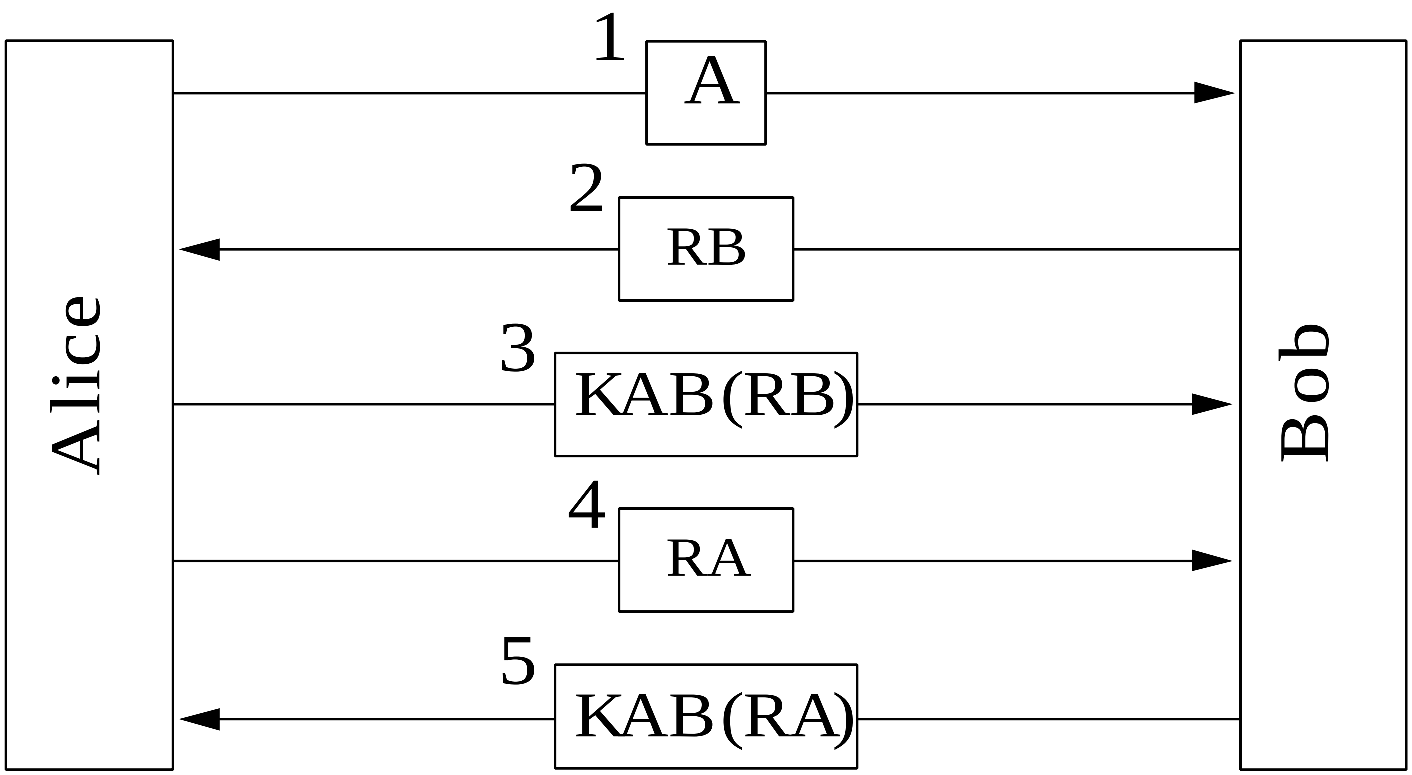
Public Key Encryption

- Split into public and private keys
  - public key used to encrypt messages
    - publish this key widely
  - private key used to decrypt messages
    - keep this key a secret
- RSA
  - algorithm for computing public/private key pairs
  - based on problems involved in factoring large primes
  - for an n bit message P, C = (P^e mod n), and P = (C^d mod n)
- Other Public Key Algorithms
  - knapsack
    - given a large collection of objects with different weights
    - public key is the total weight of a subset of the objects
    - private key is the list of objects

Authentication

- Identify the parties that wish to communicate
- Create a session key
  - a random string
  - used only for one session
- Authentication based on Shared Keys
  - each party already shares a private key
    - exchanged via an out of band transmission
  - challenge-response
    - send a random string
    - response is the encryption of the random string with the shared key

Authentication Example



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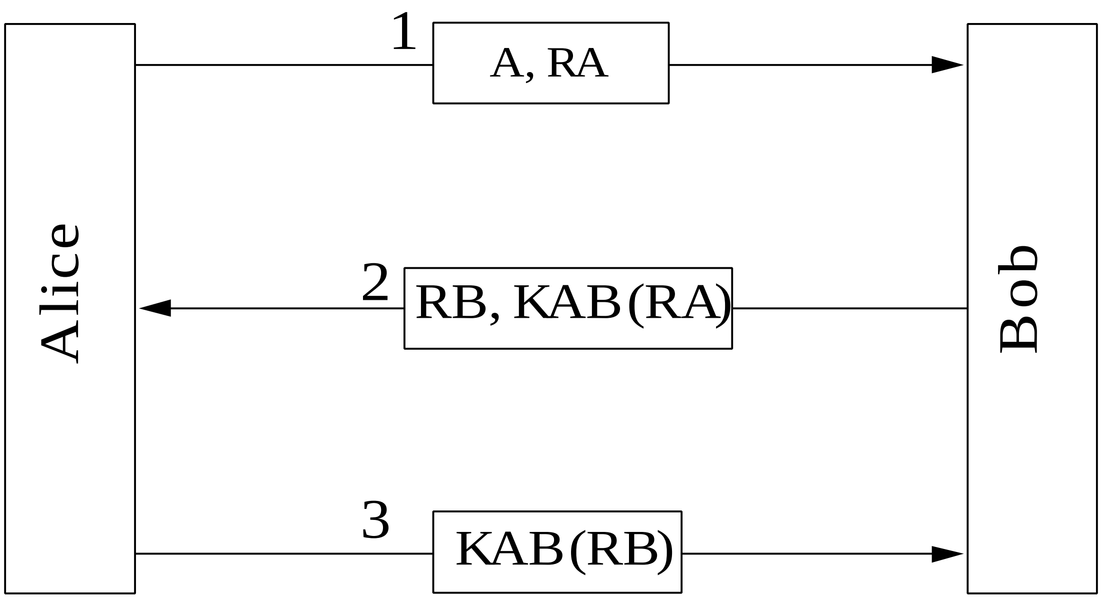
Simplified Protocol



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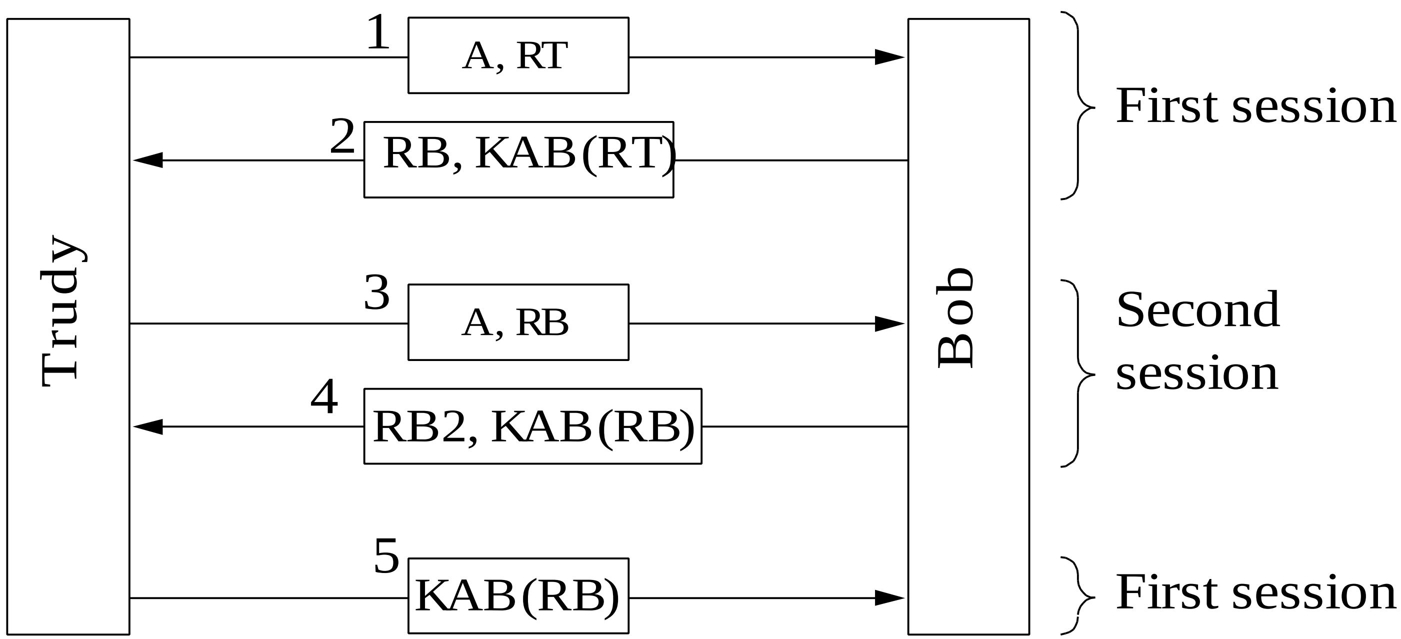
- Only requires three messages
- But it is subject to a “man in the middle attack”

Attacking the Simplified Protocol

- T can get B to respond to is own challenge
- T opens a second session with B
  - it issues B's session 1 challenge back to B in session 2



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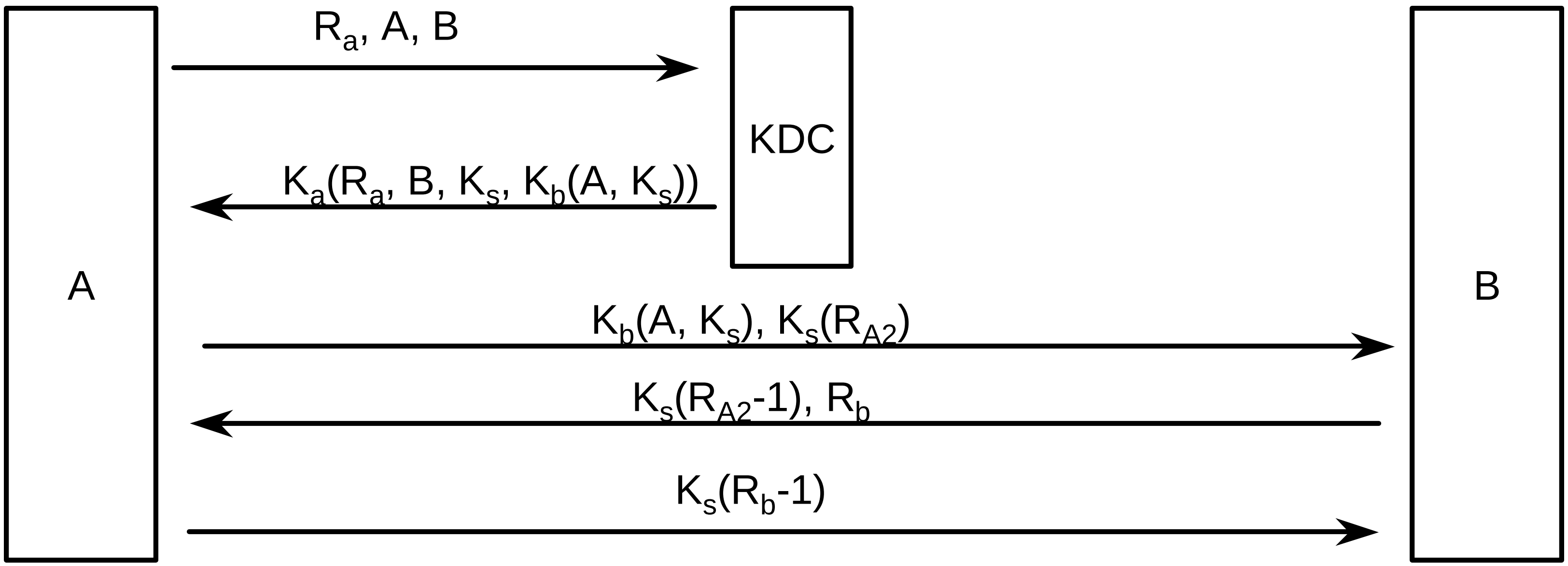
Key Distribution Center

- Problem with Private Key Authentication
  - Need to establish key
  - for n people need n^2 keys
  - keys must be established via **out-of-band** communication
- Solution: Key Distribution Center (KDC)
  - trusted party used to assist in authentication
  - each party establishes a private key with the center
- have KDC trans-code a message with a session key
  - A sends to KDC <A, $K_A(B, K_s)$>
  - KDC sends to B <$K_b(A, K_s)$>
  - open to replay attack
    - T logs KDC to B message **and** all traffic using K_s

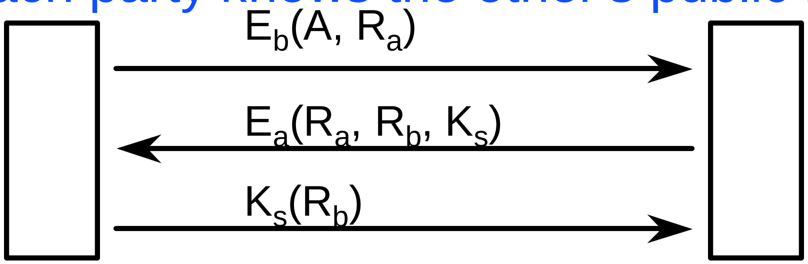
Needham-Schroeder Authentication



- R_A, R_{A2} and R_B random strings
  - used to prevent replay attacks
- If T ever gets K_s can establish contact with B
  - can prevent this with a slight variation of the algorithm
- Used in Kerberos Authentication System

Authentication using Public Keys

- Assume each party knows the other's public key



- How To learn others Public Key?
  - use a public key server
    - but how do we trust the public key server?
    - have a public key for the public key server
    - possible to have man-in-the-middle attacks
  - interlock protocol
    - only send half the message (odd bits) at a time
    - prevents man-in-the-middle attacks
    - still possible to spoof service

Digital Signatures

- Want to "sign" a message such that:
  - receiver can verify the identity of the sender
  - sender cannot repudiate the contents of the message
  - receiver cannot forge a message
- Central authority (BB)
  - A sends BB A, $K_a(B, R_a, t, P)$
  - BB sends B $K_b(A, R_a, t, P, K_{bb}(A, t, P))$
  - everyone trusts BB
    - BB can be called on to decrypt messages to verify them
    - BB need not store all message that it validates
  - t - timestamp used to prevent replay attacks
- Public Key
  - need E(D(P)) = P **and** D(E(P)) = P
  - A sends B $E_b(D_a(P))$
    - B keeps $D_a(P)$ and third party can use E_a to verify it's from A

Used to prevent replay attacks when t has not changed yet (I.e. slow clock)

Digital Signatures (cont.)

- Problems
  - Repudiation
    - inform police that the key was stolen
    - claim the “bad guy” sent the message
  - Key Changes
    - need to keep records of when keys were in use
- Standards
  - RSA Algorithm
    - popular with many commercial systems
  - El Gamal
    - NSA/NIST Standard
    - too new, and private to have trust

Message Digests

- Goal: Send Signed Plain text
  - can use slow cryptography on signature since its short
- Need:
  - Given P, easy to compute MD(P)
  - Given MD(P), impossible to find P
  - no P and P' exist such that MD(P) = MD(P')
    - use hash functions that produce >= 128 bit digest
- Operation
  - A sends P, D_a(MD(P))
- Digest Functions
  - MD5
    - produces 128 bit digest
  - SHS
    - NSA/NIST effort
    - produces 160 bit output