CIS 551 / TCOM 401

Computer and Network Security

Spring 2008

Lecture 17

Announcements

- Project 3 available on the web.
  - Get the handout in class today.
  - Project 3 is due April 4th
  - It is easier than project 1 or 2, but *don't wait to start*

- Midterm 2 is *one week* from today
  - Tuesday: April 1st.
  - Will cover all material since the last midterm.

General Definition of "Protocol"

- A *protocol* is a multi-party algorithm
  - A sequence of steps that precisely specify the actions required of the parties in order to achieve a specified objective.
- Important that there are multiple participants
- Typically a situation of heterogeneous trust
  - Alice may not trust Bart
  - Bart may not trust the network

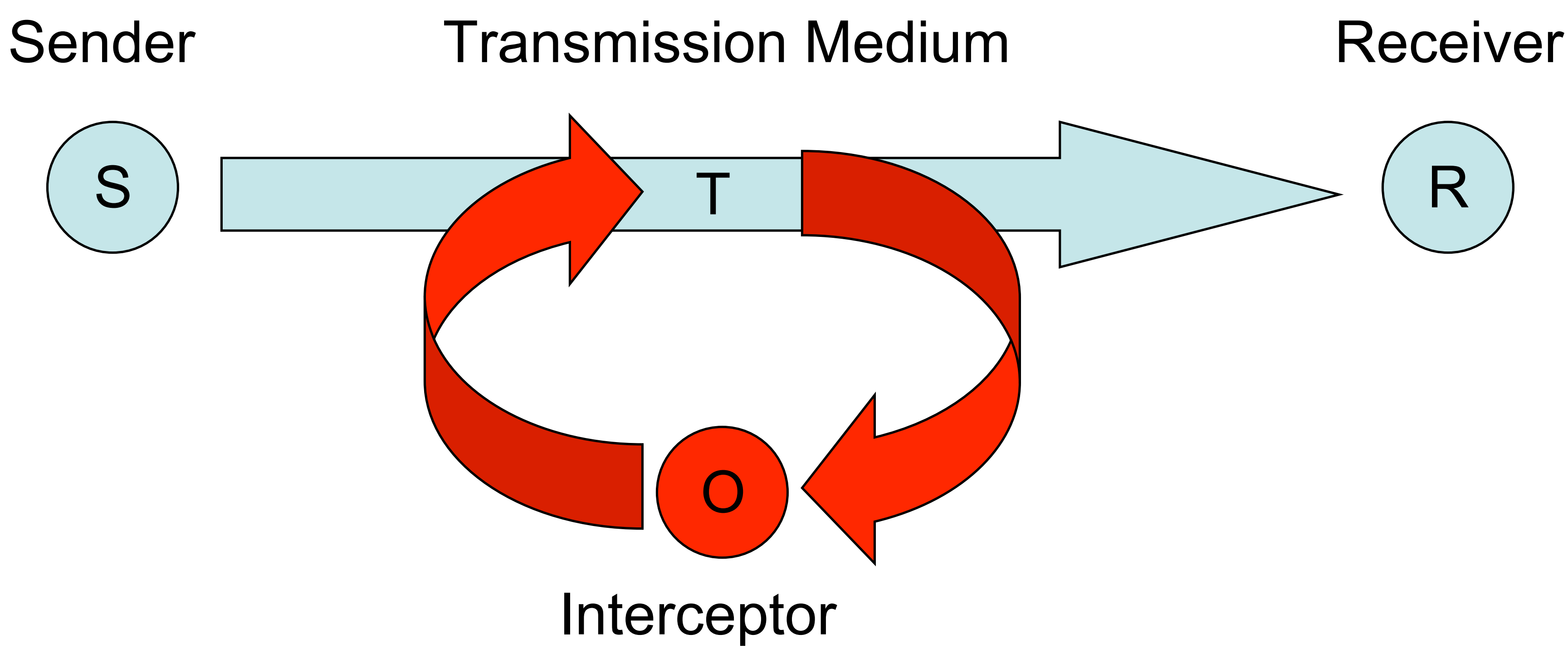
Characteristics of Protocols

- Every participant must know the protocol and the steps in advance.
- Every participant must agree to follow the protocol
  - *Honest participants*

- Big problem: How to deal with bad participants?

Cryptographic Protocols

- Consider communication over a network…
- What is the threat model?
  - What are the vulnerabilities?



What Can the Attacker Do?

- Intercept them (confidentiality)
- Modify them (integrity)
- Fabricate other messages (integrity)
- Replay them (integrity)

- Block the messages (availability)
- Delay the messages (availability)
- Cut the wire (availability)
- Flood the network (availability)

Dolev-Yao Model

- Simplifies reasoning about protocols
  - doesn't require reduction to computational complexity
- Treat cryptographic operations as "black box"
- Given a message M = (c1,c2,c3,…) attacker can deconstruct message into components c1 c2 c3
- Given a collection of components c1, c2, c3, … attacker can forge message using a subset of the components (c1,c2,c3)
- Given an encrypted object K{c}, attacker can learn c only if attacker knows decryption key corresponding to K
- Attacker can encrypt components by using:
  - fresh keys, or
  - keys they have learned during the attack

Formal Dolev-Yao Model

- A message is a finite sequence of :
  - Atomic strings, nonces, Keys (public or private), Encrypted Submessages

  M ::= a | n | K | k | K{M} | k{M} | M,M

- The attacker's (or observer's) state is a set S of messages:
  - The set of all message & message components that the attacker has seen -- the attacker's "knowledge"
  - Seeing a new message sent by an honest participant adds the new message components to the attacker's knowledge
  - If $M_1, M_2 \in S$ then $M_1 \in S$ and $M_2 \in S$
  - If $K_A\{M\} \in S$ and $K_A \in S$ then $M \in S$
  - If $K_A\{M\} \in S$ and $k_A \in S$ then $M \in S$
  - If $M \in S$ and $K \in S$ then $K\{M\} \in S$
  - If $M \in S$ and $k \in S$ then $k\{M\} \in S$

  } S closed under these operations

Using the Dolev-Yao model

- Given a description of a protocol:
  - Sequence of messages to be exchanged among honest parties.
- "Simulate" an attacked version of the protocol:
  - At each step, the attacker's knowledge state is the (closure of the) knowledge of the prior state plus the new message
  - An active attacker can create (and insert into the communication stream) any message M composed from the knowledge state S:
    - $M = M_1, M_2, \ldots, M_n$ such that $M_i \in S$
- See if the "attacked" protocol leads to any bad state
  - Example: if K is supposed to be kept secret but $K \in S$ at some point, the attacker has learned the key.

Authentication

- For honest parties, the claimant A is able to authenticate itself to the verifier B. That is, B will complete the protocol having accepted A's identity.

Shared-Key Authentication

Alice

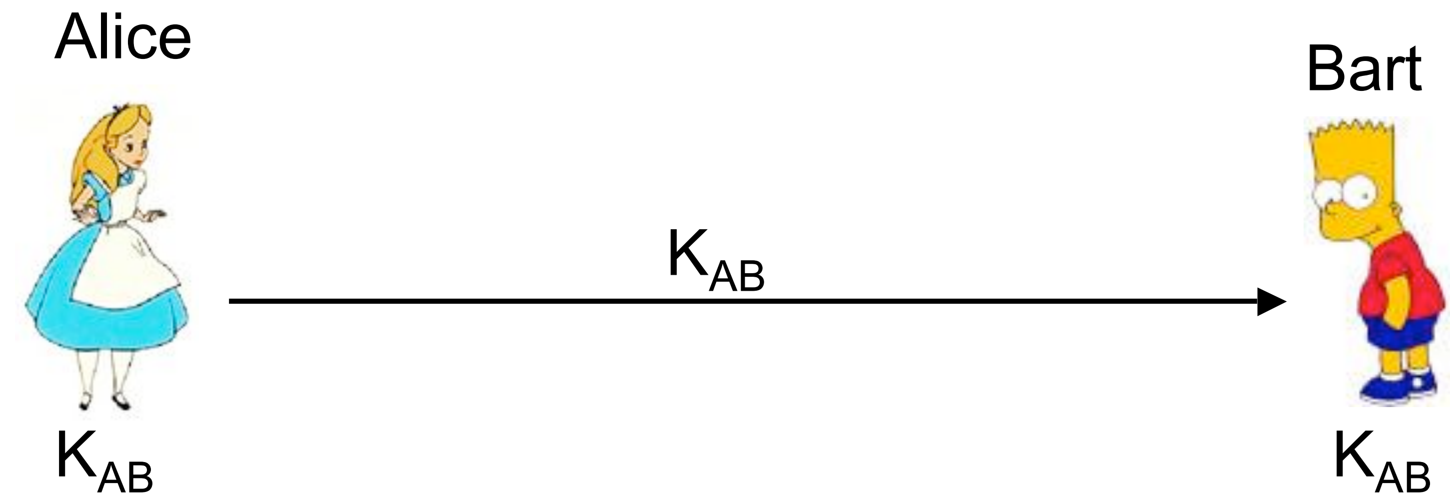
K_{AB}

Bart

K_{AB}

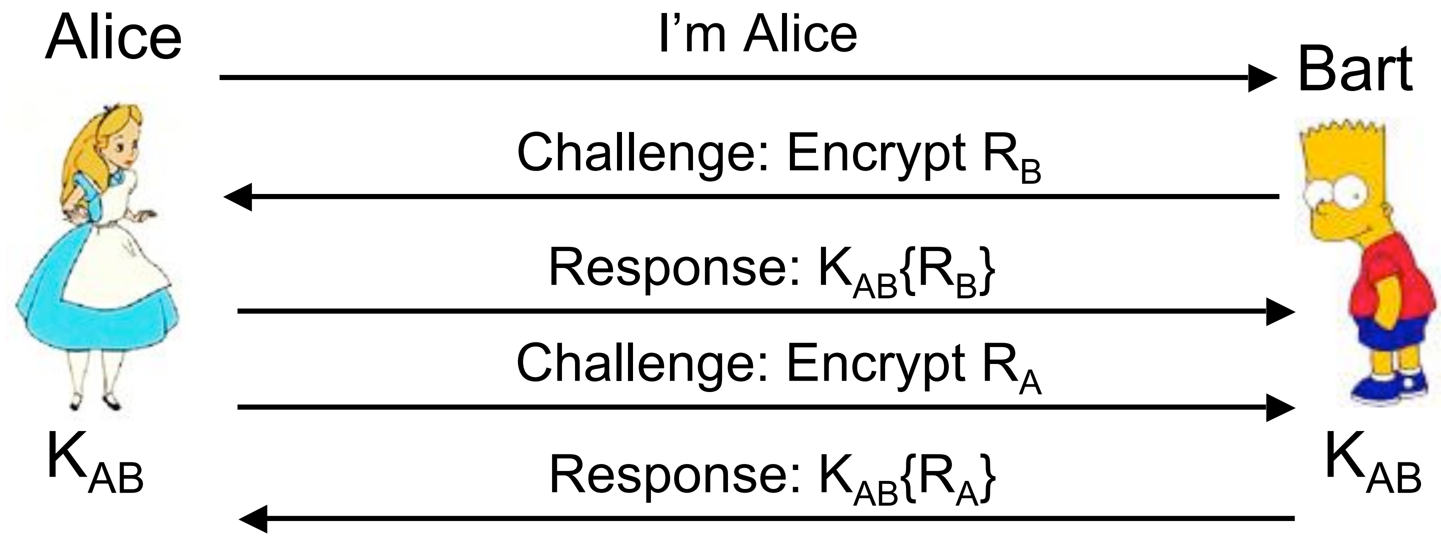
- Assume Alice & Bart already share a key K_{AB}.
  - The key might have been decided upon in person or obtained from a trusted 3rd party.
- Alice & Bart now want to communicate over a network, but first wish to authenticate to each other

Solution 1: Weak Authentication



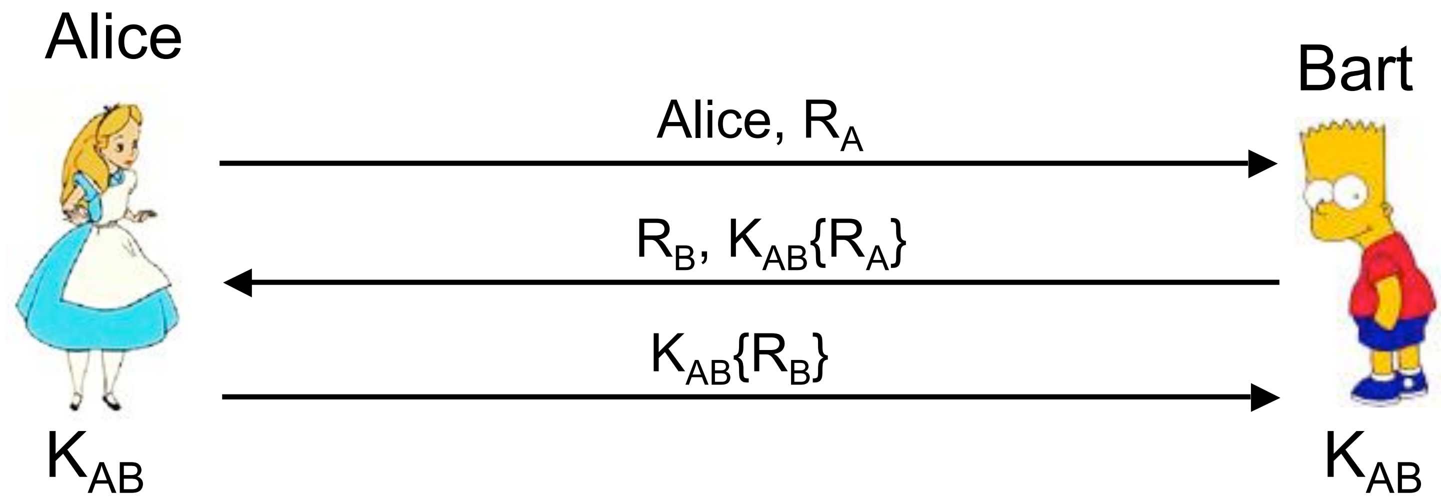
- Alice sends Bart K_{AB}.
  - K_{AB} acts as a password.
- The secret (key) is revealed to passive observers.
- Only works one-way.
  - Alice doesn't know she's talking to Bart.

Solution 2: Strong Authentication



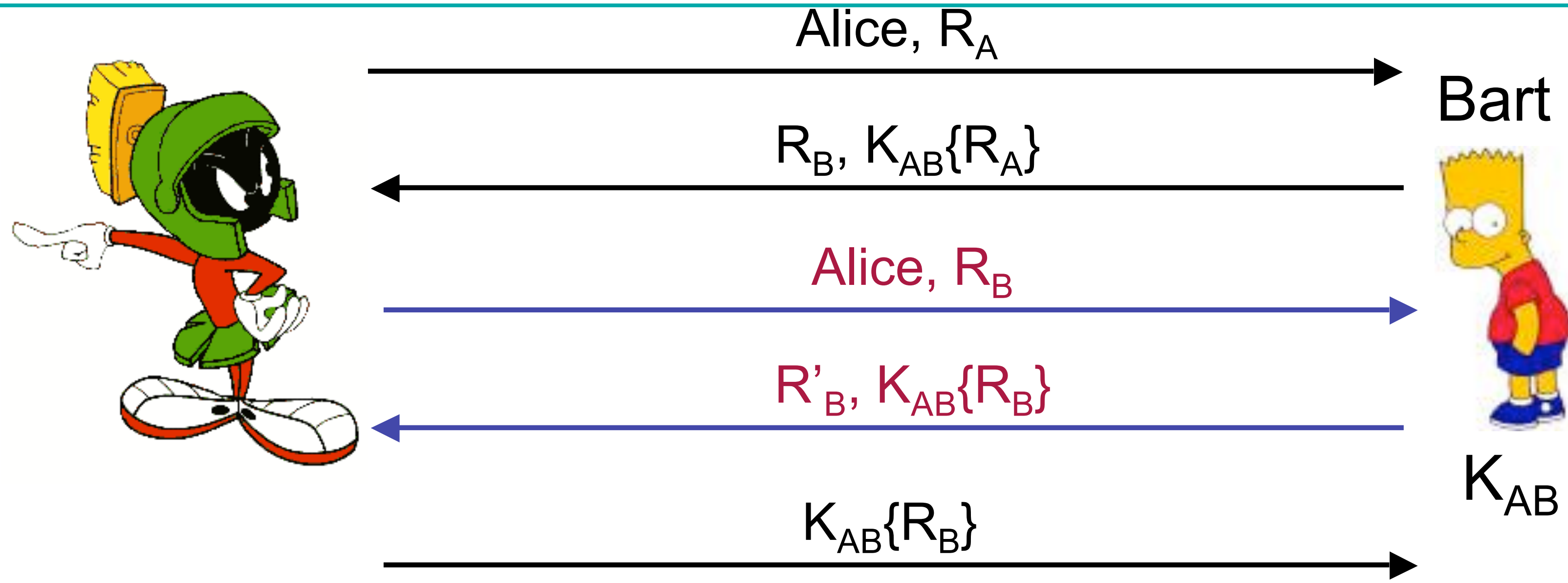
- Protocol doesn't reveal the secret.
- *Challenge/Response*
  - Bart requests proof that Alice knows the secret
  - Alice requires proof from Bart
  - R_A and R_B are randomly generated numbers

(Flawed) Optimized Version



- Why not send more information in each message?
- This seems like a simple optimization.
- But, it’s broken… how?

Attack: Marvin can Masquerade as Alice



- Marvin pretends to take the role of Alice in two runs of the protocol.
  - Tricks Bart into doing Alice's part of the challenge!
  - Interleaves two instances of the same protocol.

Lessons

- Protocol design is tricky and subtle
  - “Optimizations” aren’t necessarily good
- Need to worry about:
  - Multiple instances of the same protocol running in parallel
  - Intruders that play by the rules, mostly
- General principle:
  - Don’t do anything more than necessary until confidence is built.
  - Initiator should prove identity *before* responder takes action (like encryption)

Threats

- *Transferability:* B cannot reuse an identification exchange with A to successfully impersonate A to a third party C.

- *Impersonation:* The probability is negligible that a party C distinct from A can carry out the protocol in the role of A and cause B to accept it as having A's identity.

Assumptions

- A large number of previous authentications between A and B may have been observed.
- The adversary C has participated in previous protocol executions with A and/or B.
- Multiple instances of the protocol, possibly instantiated by C, may be run simultaneously.

Primary Attacks

- Replay.
  - Reusing messages (or parts of messages) inappropriately
- Interleaving.
  - Mixing messages from different runs of the protocol.
- Reflection.
  - Sending a message intended for destination A to B instead.
- Chosen plaintext.
  - Choosing the data to be encrypted
- Forced delay.
  - Denial of service attack -- taking a long time to respond
  - Not captured by Dolev Yao model

Primary Controls

- Replay:
  - use of challenge-response techniques
  - embed target identity in response.
- Interleaving
  - link messages in a session with chained nonces.
- Reflection:
  - embed identifier of target party in challenge response
  - use asymmetric message formats
  - use asymmetric keys.

Primary Controls, continued

- Chosen text:
  - embed self-chosen random numbers (“confounders”) in responses
  - use “zero knowledge” techniques.
- Forced delays:
  - use nonces with short timeouts
  - use timestamps in addition to other techniques.

Replay

- *Replay*: the threat in which a transmission is observed by an eavesdropper who subsequently reuses it as part of a protocol, possibly to impersonate the original sender.
  - Example: Monitor the first part of a telnet session to obtain a sequence of transmissions sufficient to get a log-in.
- Three strategies for defeating replay attacks
  - Nonces
  - Timestamps
  - Sequence numbers.

Nonces: Random Numbers

- *Nonce*: A number chosen at random from a range of possible values.
  - Each generated nonce is valid only once.
- In a challenge-response protocol nonces are used as follows.
  - The verifier chooses a (new) random number and provides it to the claimant.
  - The claimant performs an operation on it showing knowledge of a secret.
  - This information is bound inseparably to the random number and returned to the verifier for examination.
  - A timeout period is used to ensure “freshness”.

Time Stamps

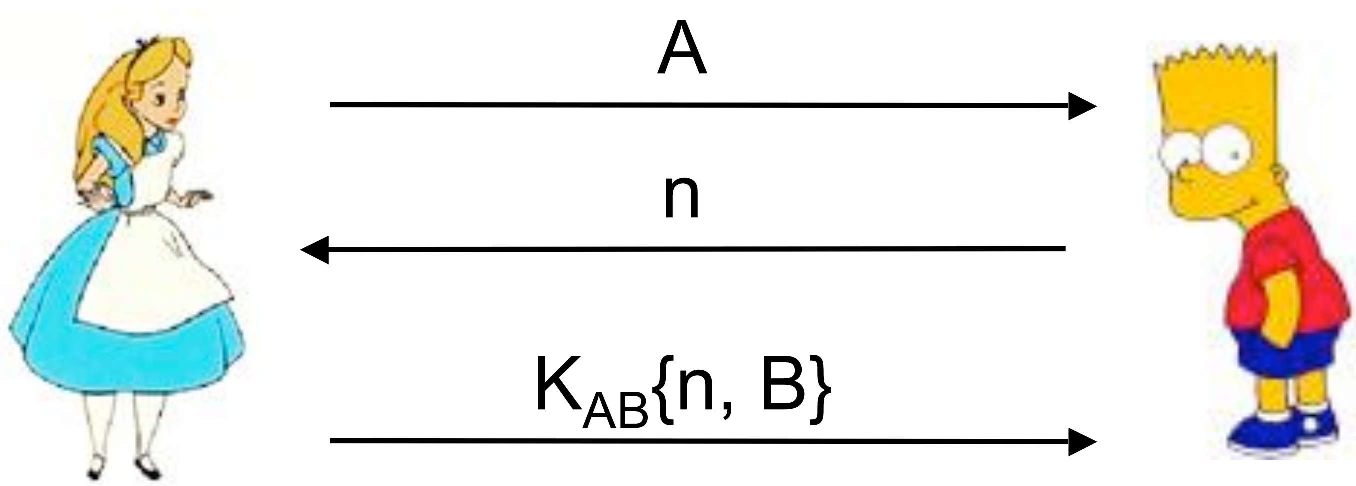
- The claimant sends a message with a timestamp.
- The verifier checks that it falls within an acceptance window of time.
- The last timestamp received is held, and identification requests with older timestamps are ignored.
- Good only if clock synchronization is close enough for acceptance window.

Sequence Numbers

- Sequence numbers provide a sequential or monotonic counter on messages.
- If a message is replayed and the original message was received, the replay will have an old or too-small sequence number and be discarded.
- Cannot detect forced delay.
- Difficult to maintain when there are system failures.

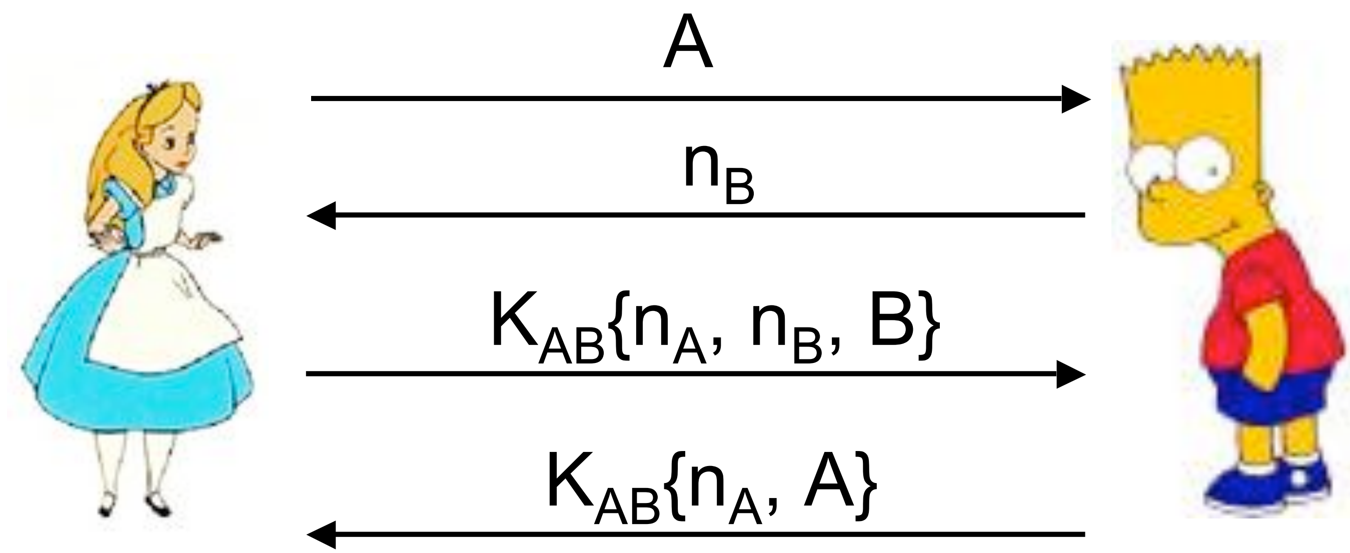
Unilateral Symmetric Key

- Unilateral = one way authentication
- Unilateral authentication with nonce.



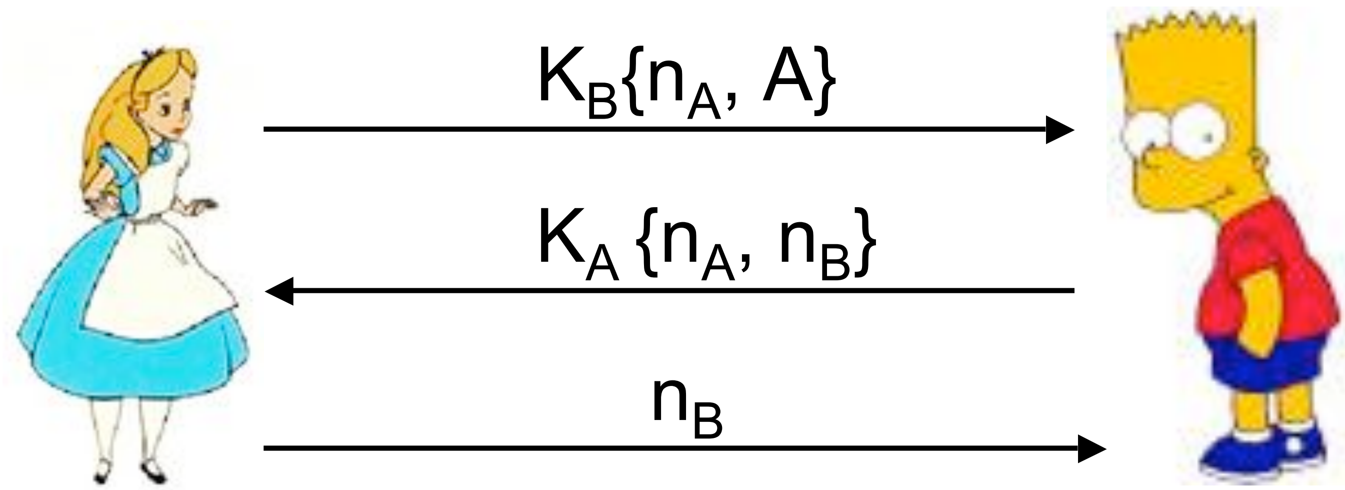
Mutual Symmetric Key

- Mutual = two way authentication
- Using Nonces:



Mutual Public Key Decryption

- Exchange nonces



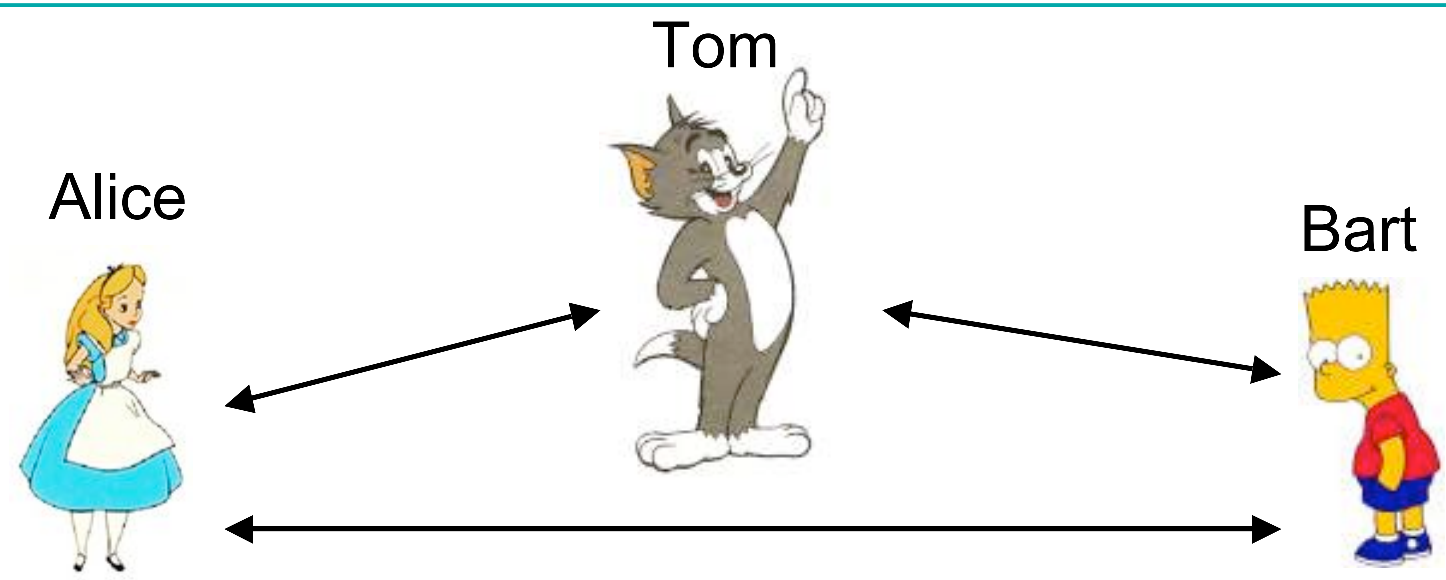
Usurpation Attacks

- Identification protocols corroborate the identity of an entity only at a given instant in time.
  - An attacker could "hijack" a session after authentication.
- Techniques to assure ongoing authenticity:
  - Periodic re-identification.
  - Tying identification to an ongoing integrity service. For example: key establishment and encryption.

General Principles

- Don't do anything more than necessary until confidence is built.
  - Initiator should prove identity before the responder does any "expensive" action (like encryption)
- Embed the intended recipient of the message in the message itself
- Principal that generates a nonce is the one that verifies it
- Before encrypting an untrusted message, add "salt" (i.e. a nonce) to prevent chosen plaintext attacks
- Use asymmetric message formats (either in "shape" or by using asymmetric keys) to make it harder for roles to be switched

Arbitrated Protocols

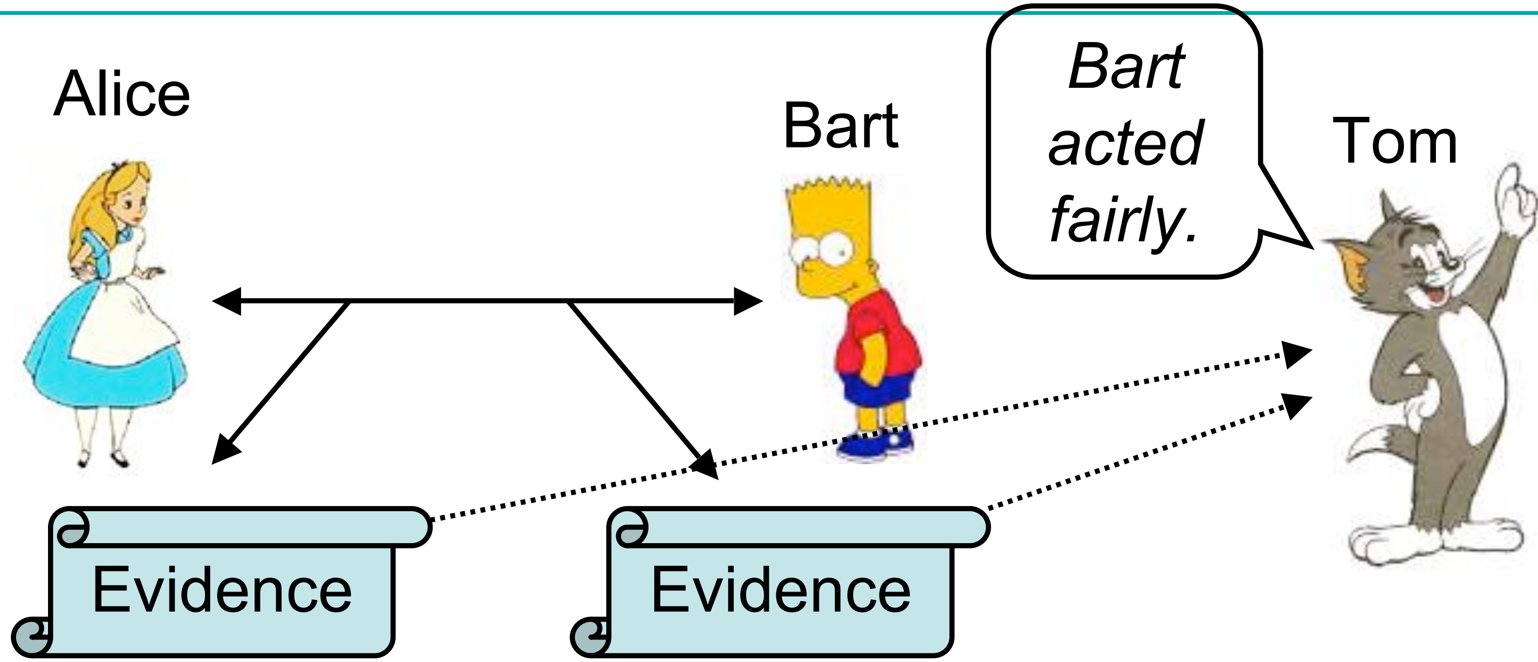


- Tom is an *arbiter*
  - Disinterested in the outcome (doesn't play favorites)
  - Trusted by the participants (Trusted 3rd party)
  - Protocol can't continue without T's participation

Arbitrated Protocols (Continued)

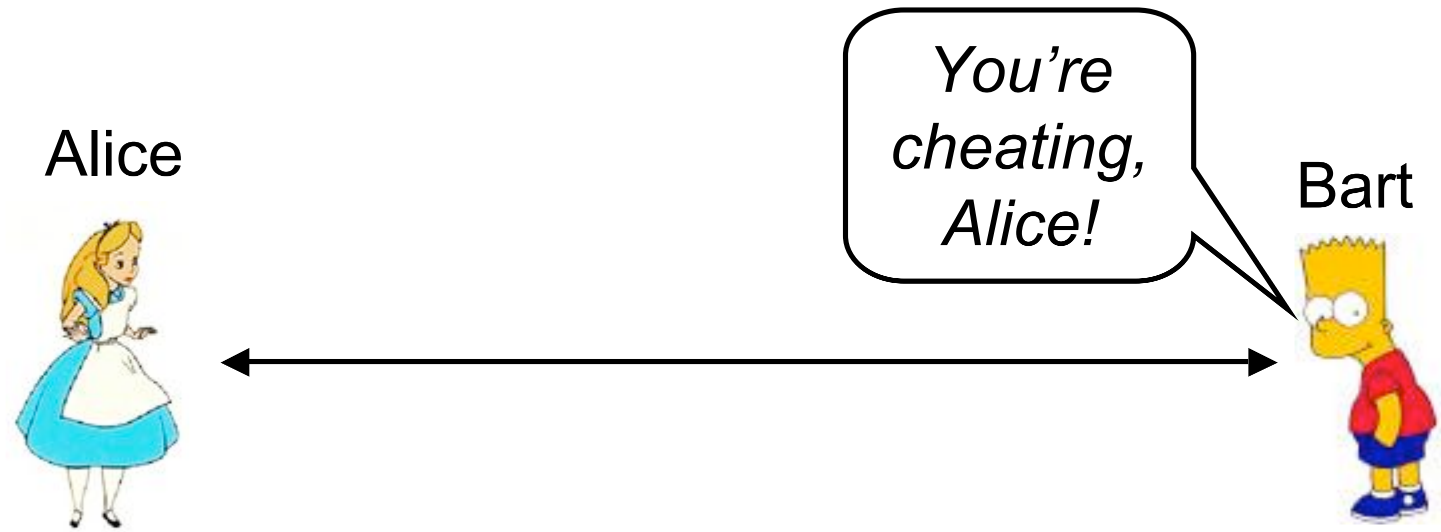
- Real-world examples:
  - Lawyers, Bankers, Notary Public
- Issues:
  - Finding a trusted 3rd party
  - Additional resources needed for the arbitrator
  - Delay (introduced by arbitration)
  - Arbitrator might become a bottleneck
  - Single point of vulnerability: attack the arbitrator!

Adjudicated Protocols



- Alice and Bard record an *audit log*
- Only in exceptional circumstances to they contact a trusted 3rd party. (3rd party is not always needed.)
- Tom as the *adjudicator* can inspect the evidence and determine whether the protocol was carried out fairly

Self-Enforcing Protocols



- No trusted 3rd party involved.
- Participants can determine whether other parties cheat.
- Protocol is constructed so that there are no possible disputes of the outcome.