CS530
Key Management & Distribution

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http://merlot.usc.edu/cs530-s10

Using Cryptography

- Provides foundation for security services
  - touched upon one form of key exchange
- But can it bootstrap itself?
  - must establish shared key
  - straightforward plan
    - one side generates key
    - transmits key to other side
    - but how?

Two Problems

- Peer-to-peer key sharing
- Prob 1: Known peer, insecure channel
- Prob 2: Secure channel, unknown peer

Man in the Middle of DH

- DH provides key exchange, but no authentication
  - you don't really know you have a secure channel
  - man-in-the-middle
  - you exchange a key with eavesdropper (man-in-the-middle), who exchanges key with the person you think are you talking to directly
  - eavesdropper relays all messages, but observes or changes them in transit
  - solutions
    - published public values
    - authenticated DH (signed or encrypt DH value)
    - encrypt the DH exchange
    - subsequently send has of DH value, with secret

Security Through Obscurity?

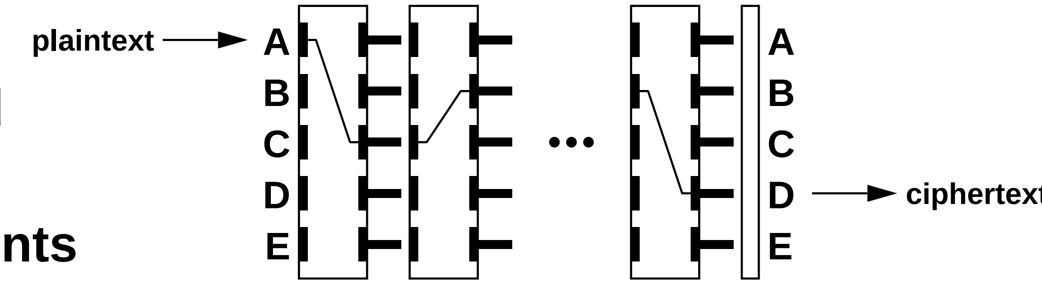
- Caesar ciphers
  - very simple permutation
  - only 25 different cases
  - relies strictly on no one knowing the method
  - key exchange is really method exchange

Passwords

- Reduces permutation space to key space
  - Caesar cipher: one-letter "key"
  - 10-letter key for MSC reduces 26! (~4×10^{20}) to ${}_{26}P_{10}$
    - but hard to remember 10-letter key
  - 8-byte key for DES reduces 2^{64}! (~$10^{10^{200}}$) to 2^{56} (~10^{17})
- But key is more compact and perhaps more readily exchanged out of band
  - in person
  - by telephone (especially for public keys)
- Most security depends on some out of band bootstrap
  - exceptions? are they really exceptions?
    - DH provided key exchange, but not authentication

The German Enigma Machine

- *Rotor*-based
  - rotors are wired codewheels
  - a rotor implements a fixed mono-alphabetic substitution
  - *polyalphabetic substitution* (with a long period) - the encipherment of each plaintext character causes various rotors to move, like an odometer (but not exactly)



- Broken first by Polish, then by English
  - not as easily as widely regarded
- Weaknesses in key distribution
  - day keys plus scramblers (using subkeys)
  - "session keys" encrypted in duplicate
  - Enigma did not use OFB/CFB

Secret Key Distribution

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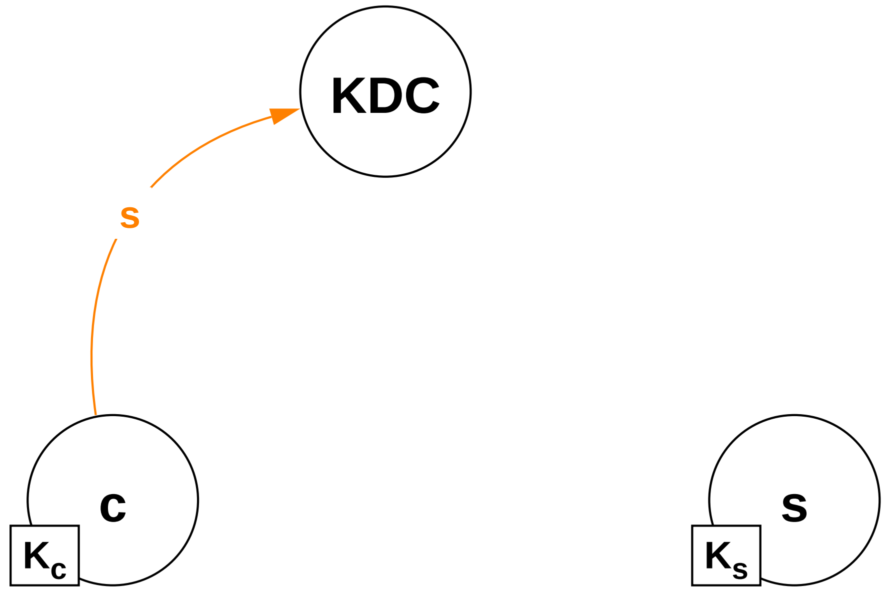
Peer-to-Peer Distribution

- Technically easy
  - by hand!
  - or have a day key
- But it doesn't scale
  - hundreds of servers...
  - times thousands of users...
  - yields ~ million keys
- Centralized key server
  - building up to the *Needham-Schroeder* approach

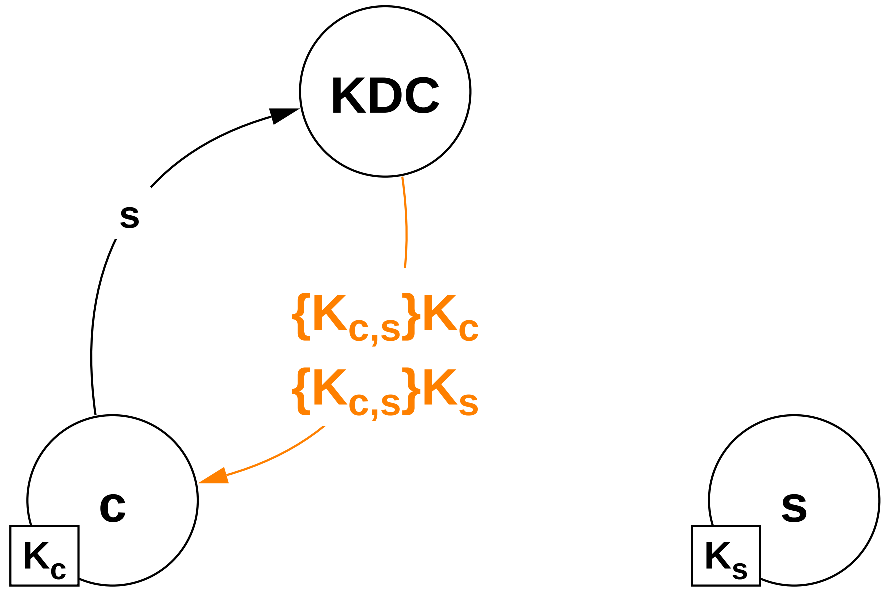
Needham and Schroeder - Basic Idea

- User sends request to KDC: {s}
- KDC generates a random key: $K_{c,s}$
  - encrypted twice, each with a different key
    - $\{K_{c,s}\}K_c$, $\{K_{c,s}\}K_s$
    - $\{K_{c,s}\}K_c$ is the ***credentials*** (contains session key)
    - $\{K_{c,s}\}K_s$ is the ***ticket***
    - ticket is ***opaque*** to the client, it is meant to be forwarded with application request
- No keys ever traverse the net in the clear

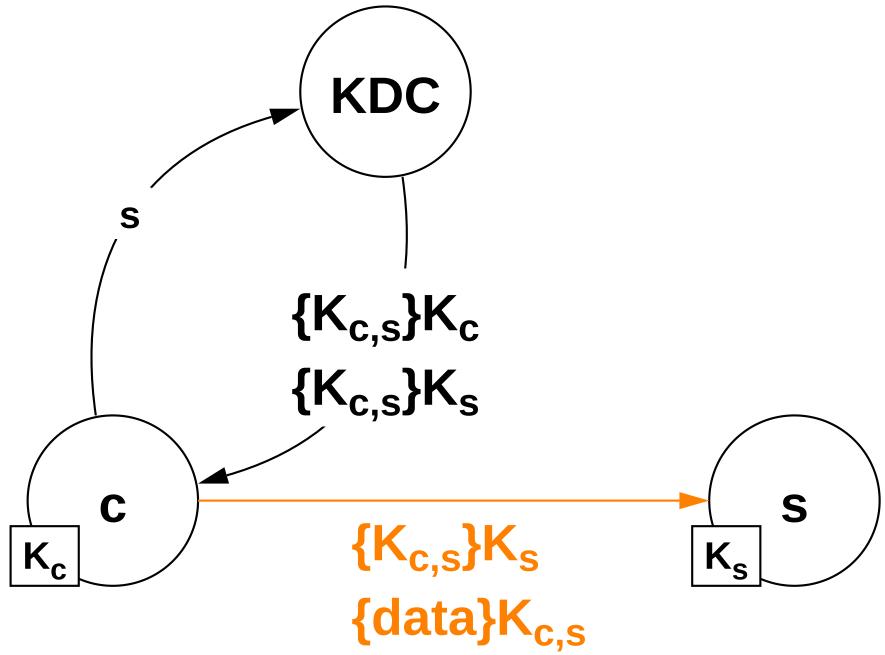
KDC



KDC (Cont...)



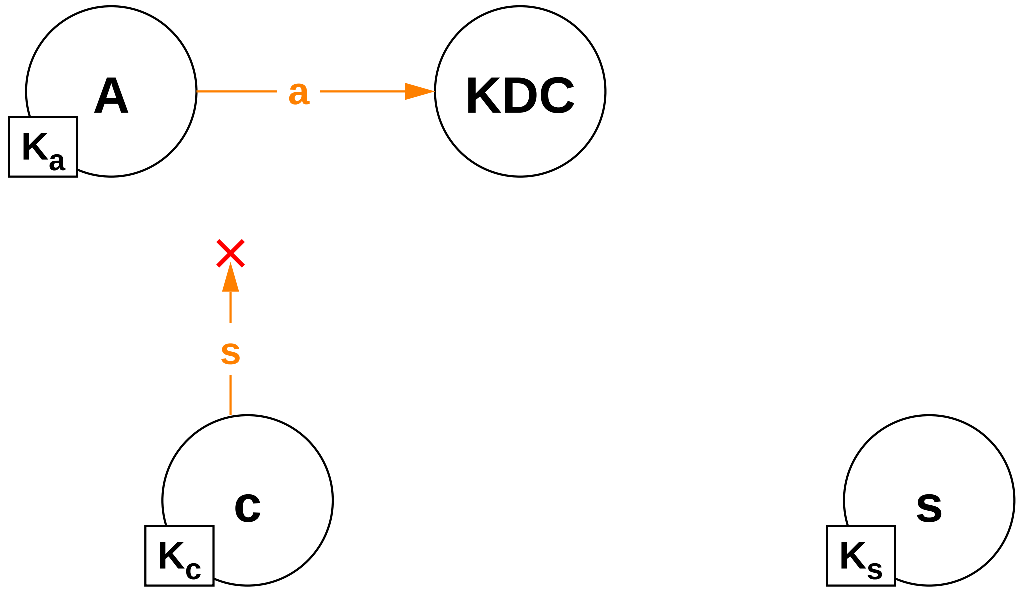
KDC (Cont...)



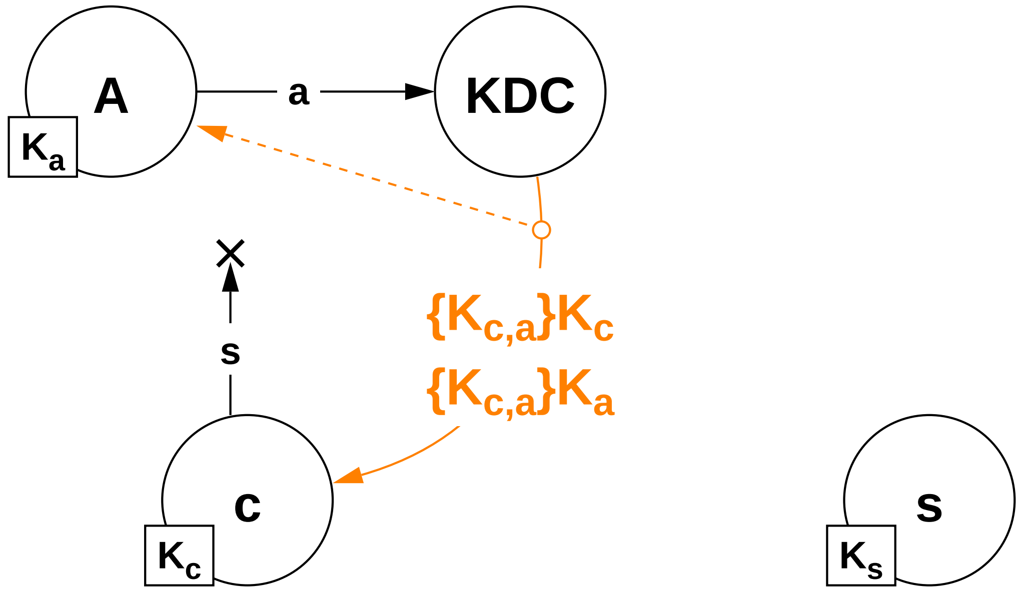
Problem #1

- How does user know session key is encrypted for the server? And vice versa?
- Attacker intercepts initial request, and substitutes own name for server
  - can now read all of user's messages intended for server

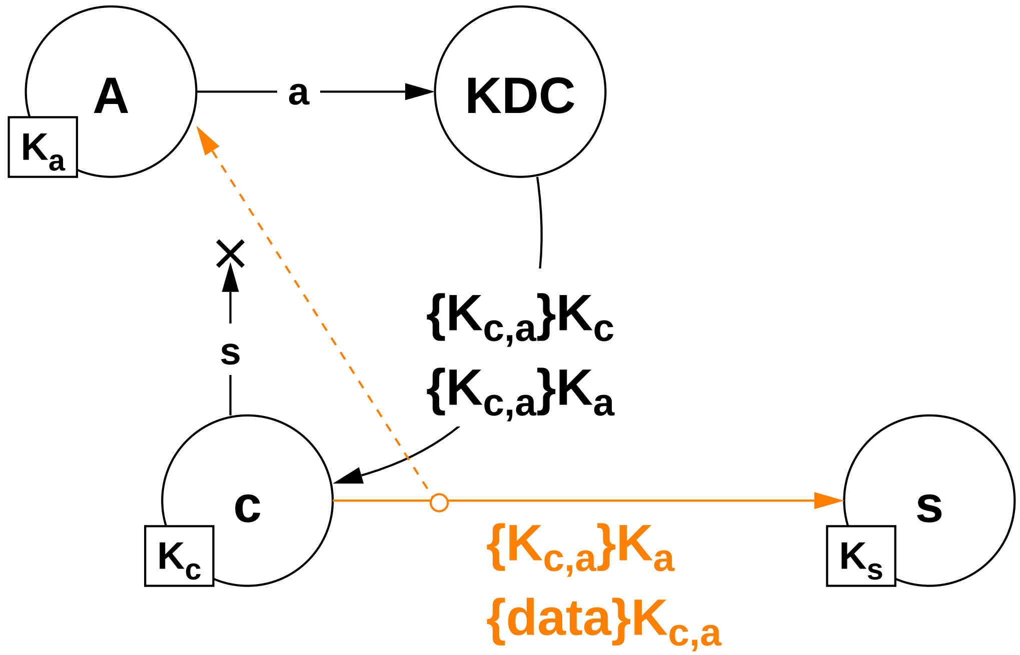
Problem #1 (Cont...)



Problem #1 (Cont...)

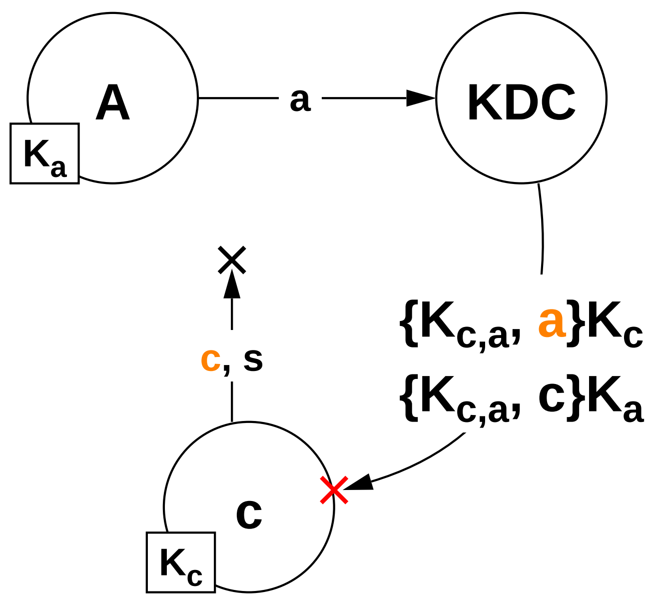


Problem #1 (Cont...)



Solution #1

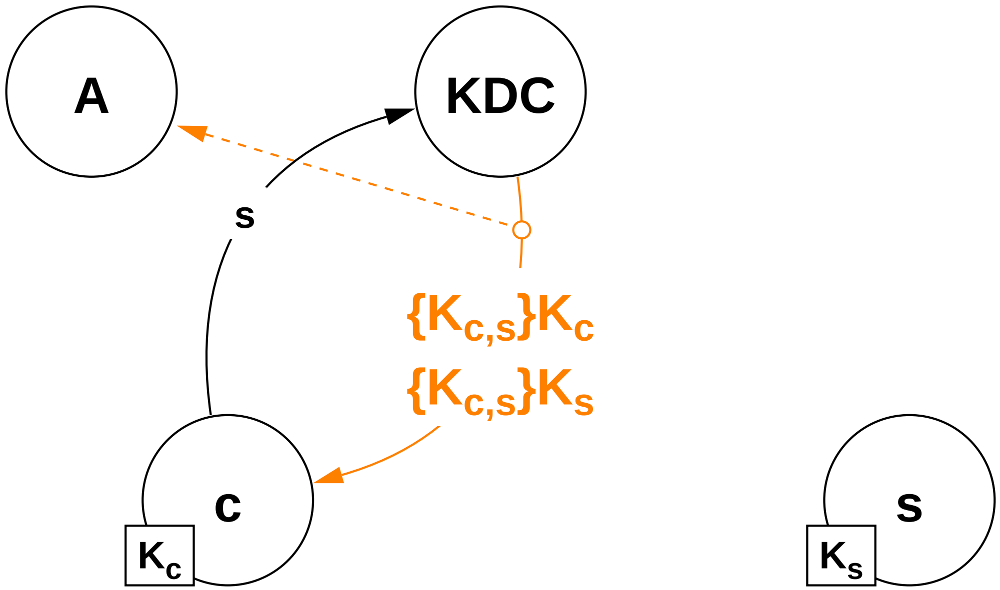
- Add names to ticket, credentials
  - request looks like {c, s}
  - $\{K_{c,s}, s\}K_c$ and $\{K_{c,s}, c\}K_s$, respectively
- Both sides can verify intended target for key sharing
- This is basic *Needham-Schroeder*



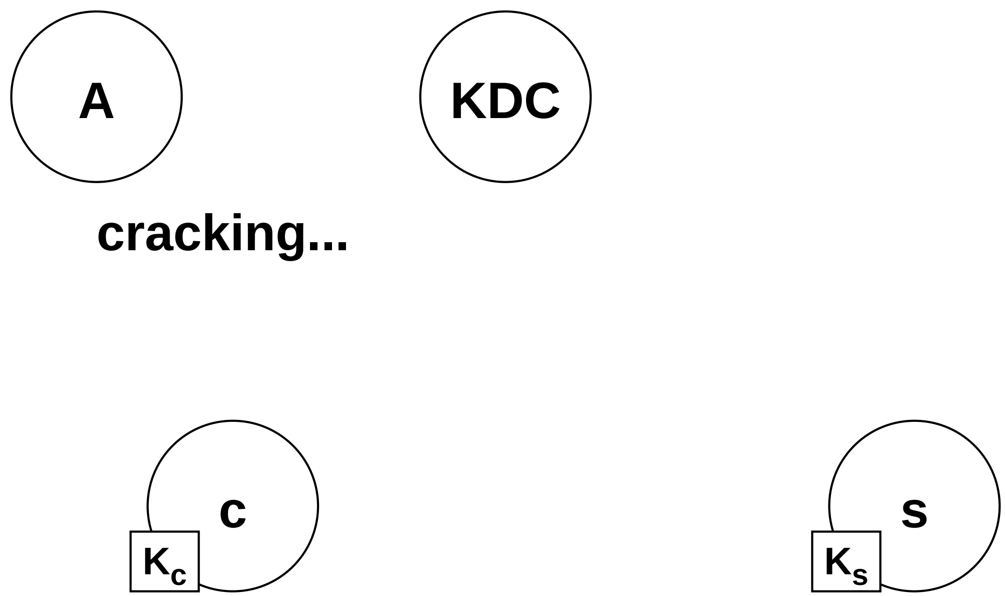
Problem #2

- How can user and server know that session key is fresh?
- Attacker intercepts and records old KDC reply, then inserts this in response to future requests
  - can now read all traffic between user and server

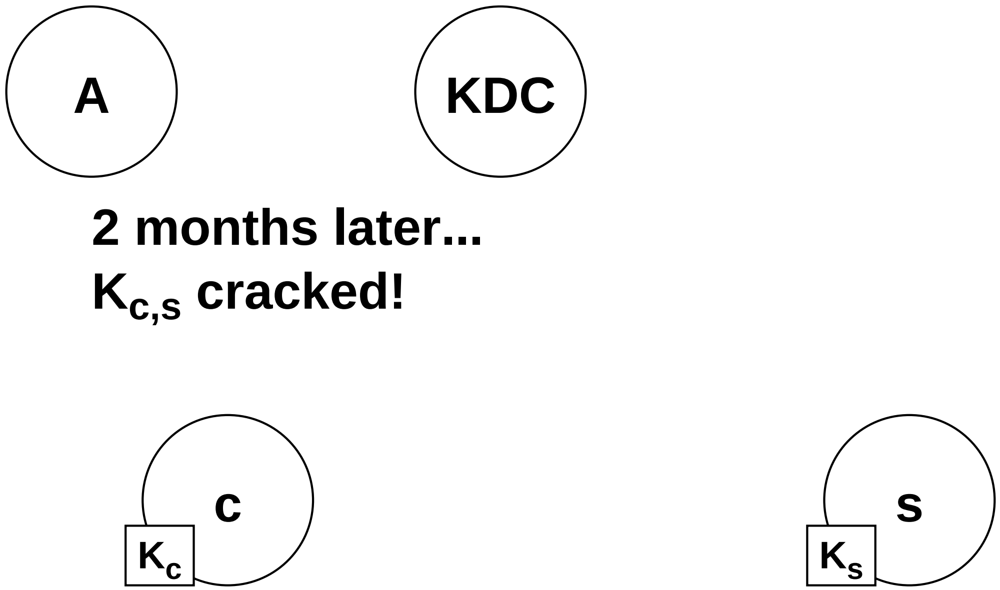
Problem #2 (Cont...)



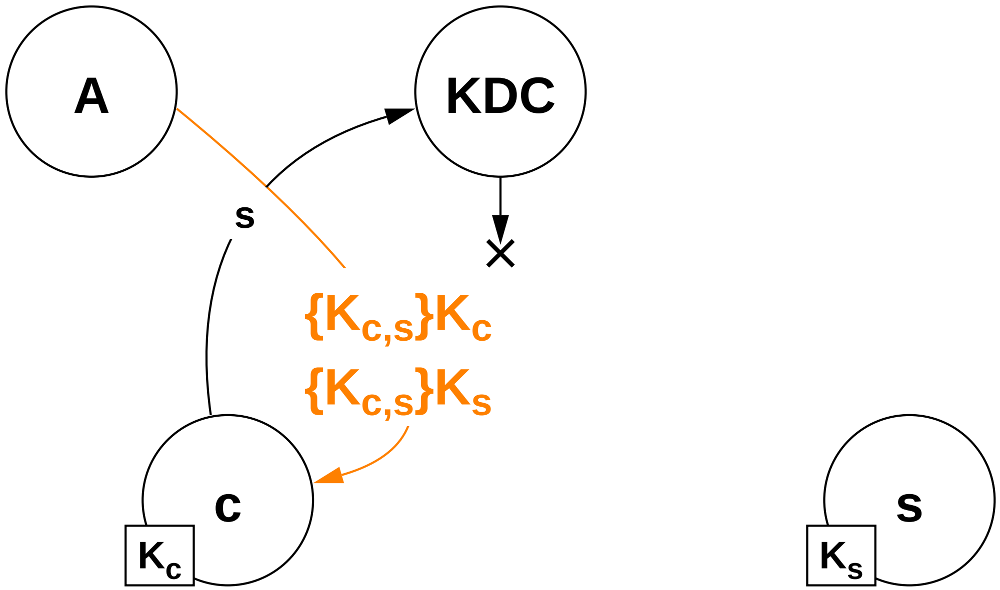
Problem #2 (Cont...)



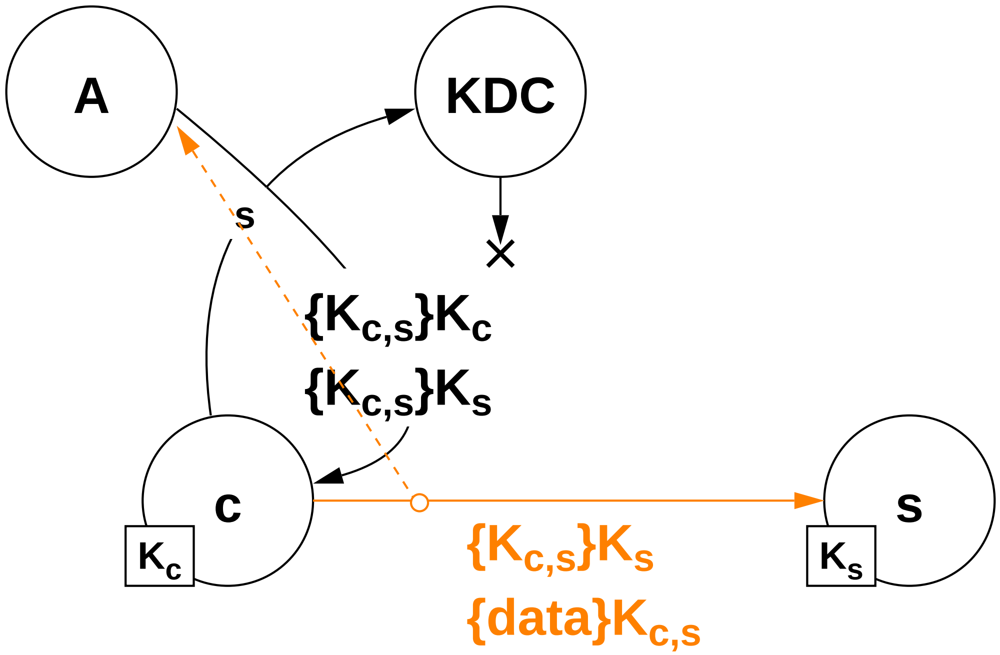
Problem #2 (Cont...)



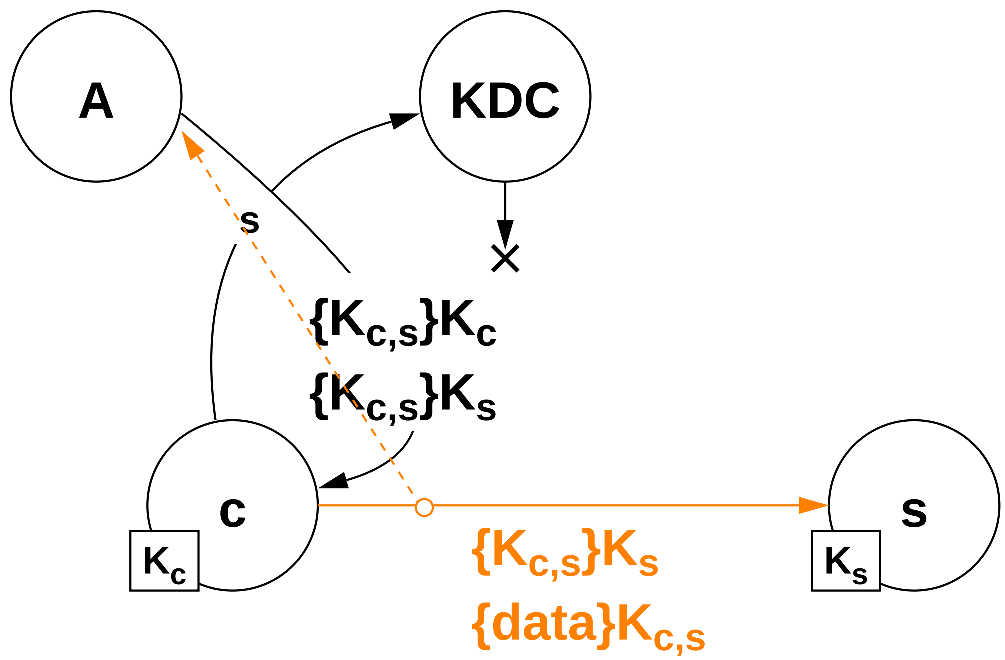
Problem #2 (Cont...)



Problem #2 (Cont...)



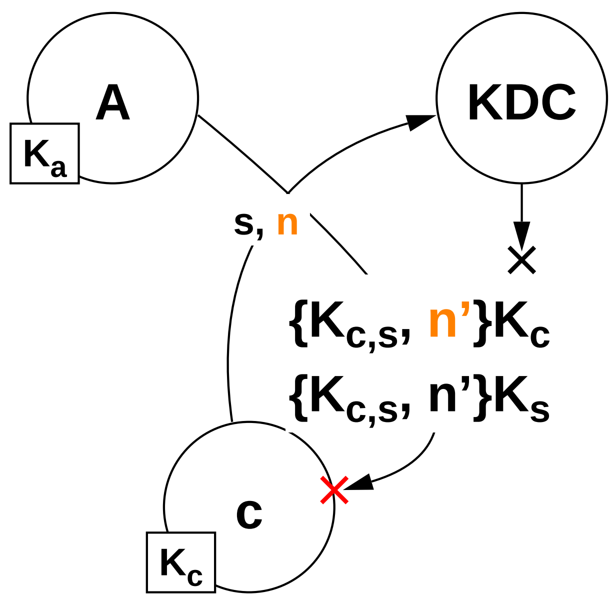
Problem #2 (Cont...)



- even if the attacker has not cracked $K_{c,s}$, simply replaying the credentials can obtained more ciphertext $\{data\}K_{c,s}$ to help it crack $K_{c,s}$

Solution #2

- Add *nonces* to ticket, credentials
  - request looks like {c, s, n}
  - $\{K_{c,s}, s, n\}K_c$ and $\{K_{c,s}, c, n\}K_s$
- Client can now check that reply made in response to current request



Problem #3

- User now trusts credentials
- But can server trust user?
- How can server tell this isn't a 3rd-party replay?
- Legitimate user makes electronic payment to attacker; attacker replays message to get paid multiple times
  - attacker can spoof IP address and impersonate the client
  - requires no knowledge of session key

Solution #3

- Add *challenge-response*
  - server generates second random nonce
  - sends to client, encrypted in session key
  - client must decrypt, decrement, encrypt
    - if the attacker does not know the session key, it cannot respond
- Effective, but adds second round of messages

Problem #4

- What happens if attacker does get session key?
  - can reuse old sessions key to answer challenge-response, generate new requests, etc.

Solution #4

- Replace (or supplement) nonce in request/reply with timestamp [Denning, Sacco]
  - $\{K_{c,s}$, s, n, t$\}K_c$ and $\{K_{c,s}$, c, n, t$\}K_s$, respectively
  - also send $\{t'\}K_{c,s}$ as ***authenticator***, each time the client sends a message to the server with the current time t'
    - prevents replay without employing second round of messages as in challenge-response

Problem #5

- Each client to KDC request yeilds new known-plaintext pair
  - or in this case, verifiable plaintext pair
    - either because the format of data is known or because message conforms to protocol structure
- Attacker can sit on the network, harvest client request and KDC replies

Solution #5

- Introduce Ticket Granting Server (TGS)
  - daily ticket plus session keys
  - session keys are random numbers
- *TGS+AS = KDC*
  - this is modified Needham-Schroeder
  - basis for *Kerberos*

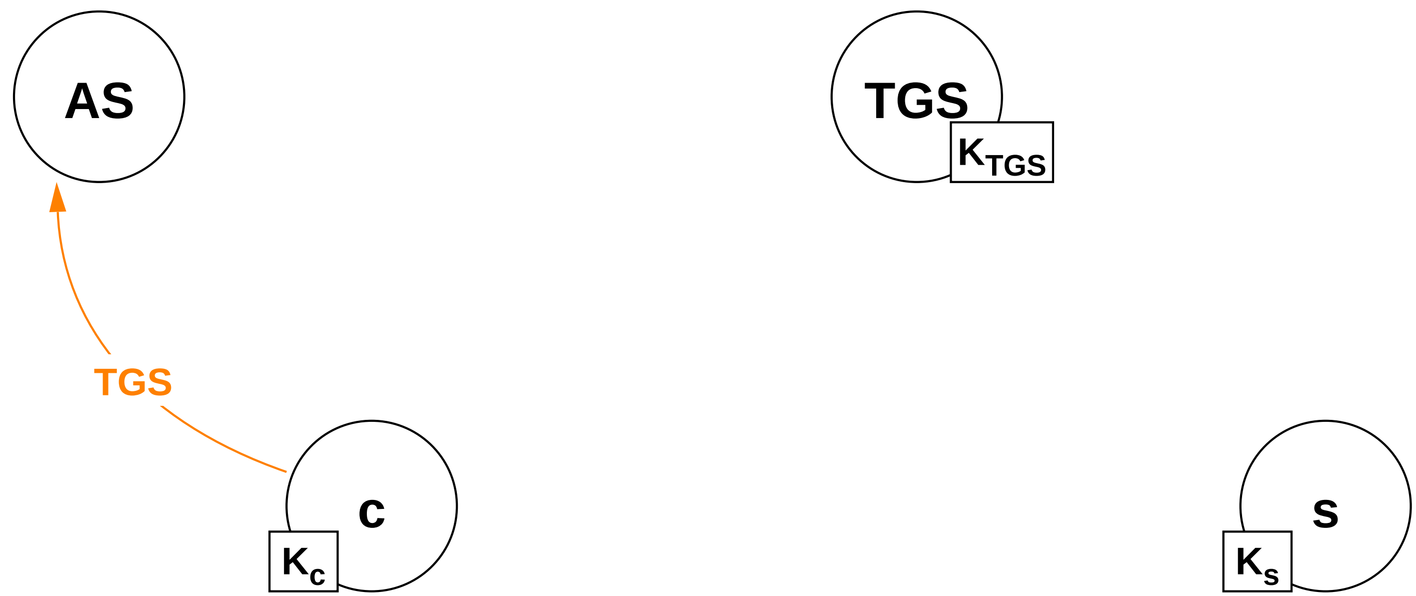
Problem #6

- Active attacker can obtain arbitrary numbers of known-plaintext pairs
  - can then mount dictionary attack at leisure
  - exacerbated by bad password selection
- K_C is often weak since it's usually derived from a passphrase

Solution #6

- Must reduce the exposure of the long-term client key K_c
- *Preauthentication*
  - establish weak authentication for user before KDC replies
  - Ex:
    - password-encrypted timestamp
    - hardware authentication
    - single-use key
  - now the attacker must wait for the client to communicate with the KDC in order to obtain known-plaintext pairs

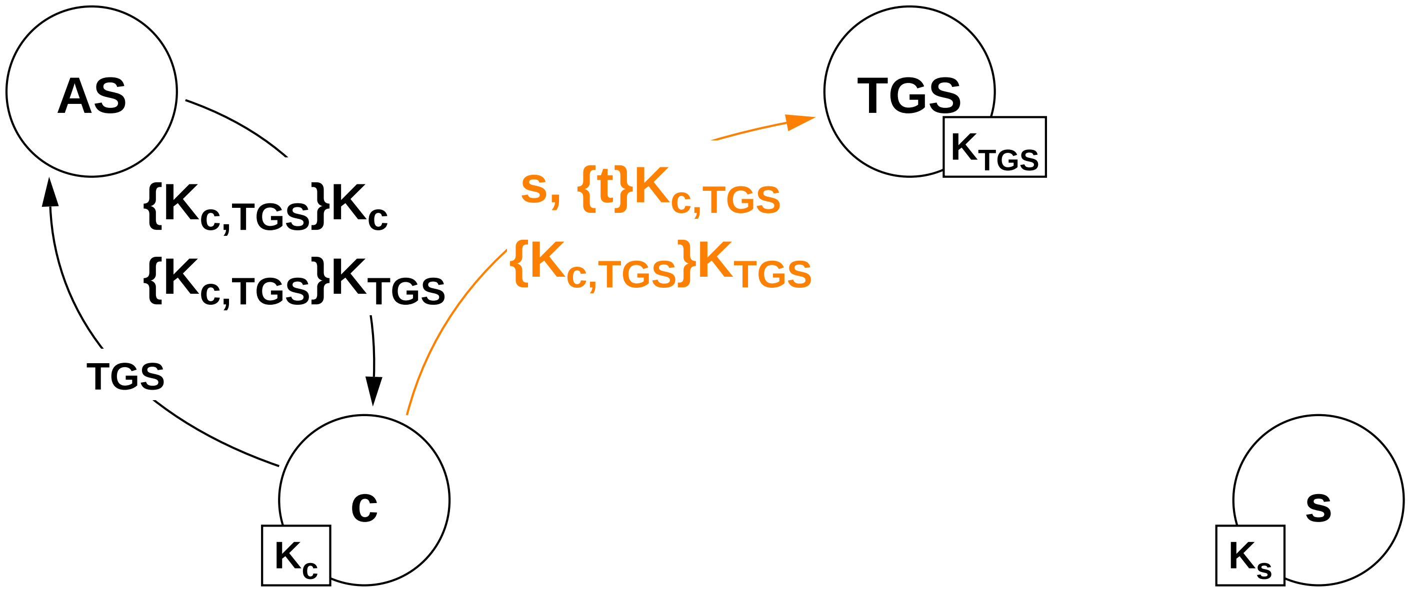
TGS



TGS (Cont...)

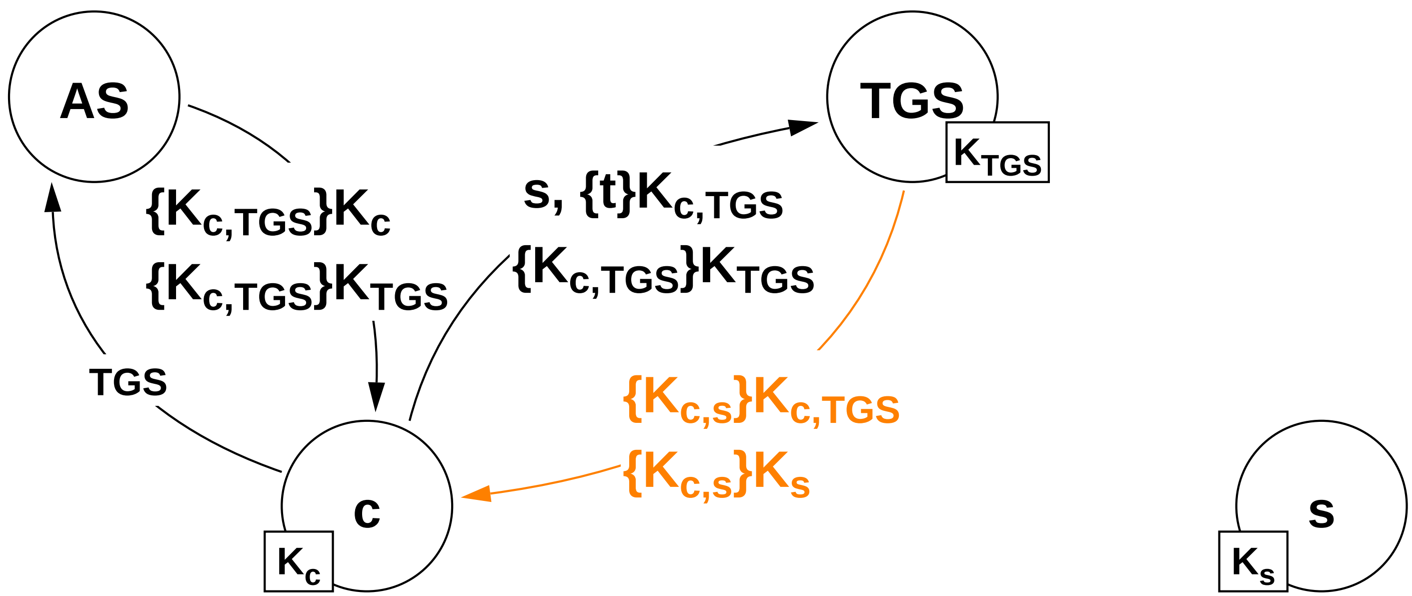
- $K_{c,TGS}$ has a ***short lifetime*** (say 8-10 hours)
- $\{K_{c,TGS}\}K_{TGS}$ is known as the ***ticket-granting-ticket (TGT)***

TGS (Cont...)



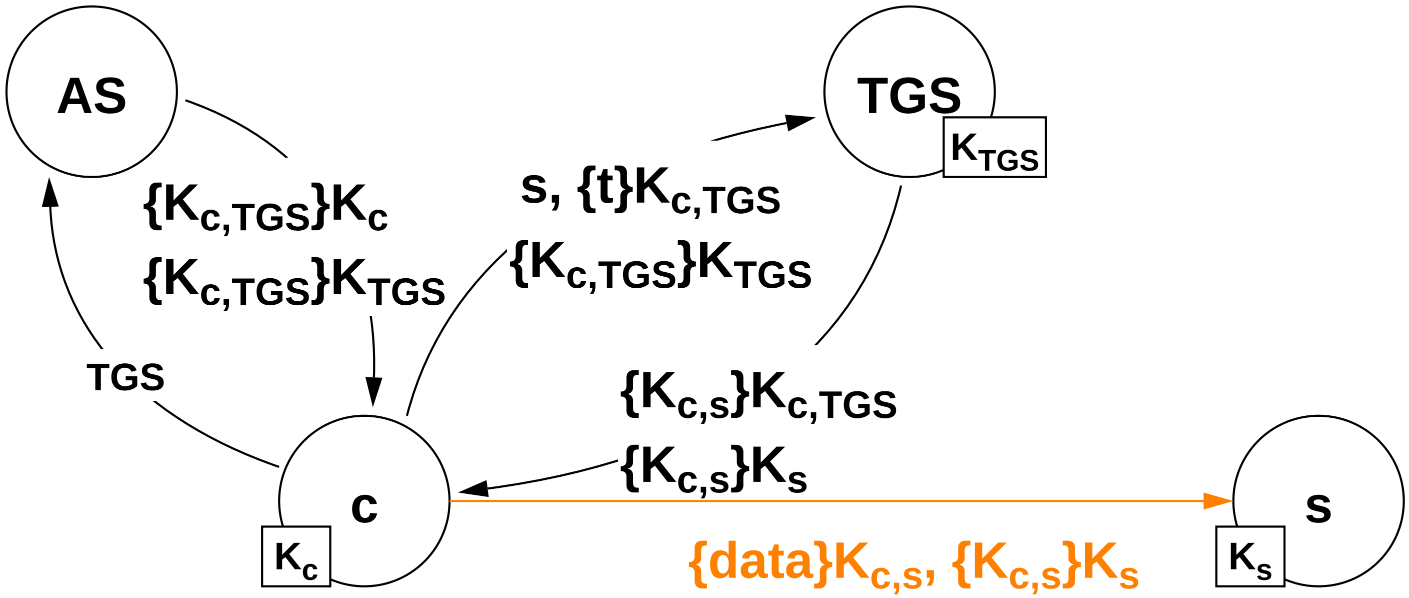
- use the TGT to get a ticket for the server s

TGS (Cont...)

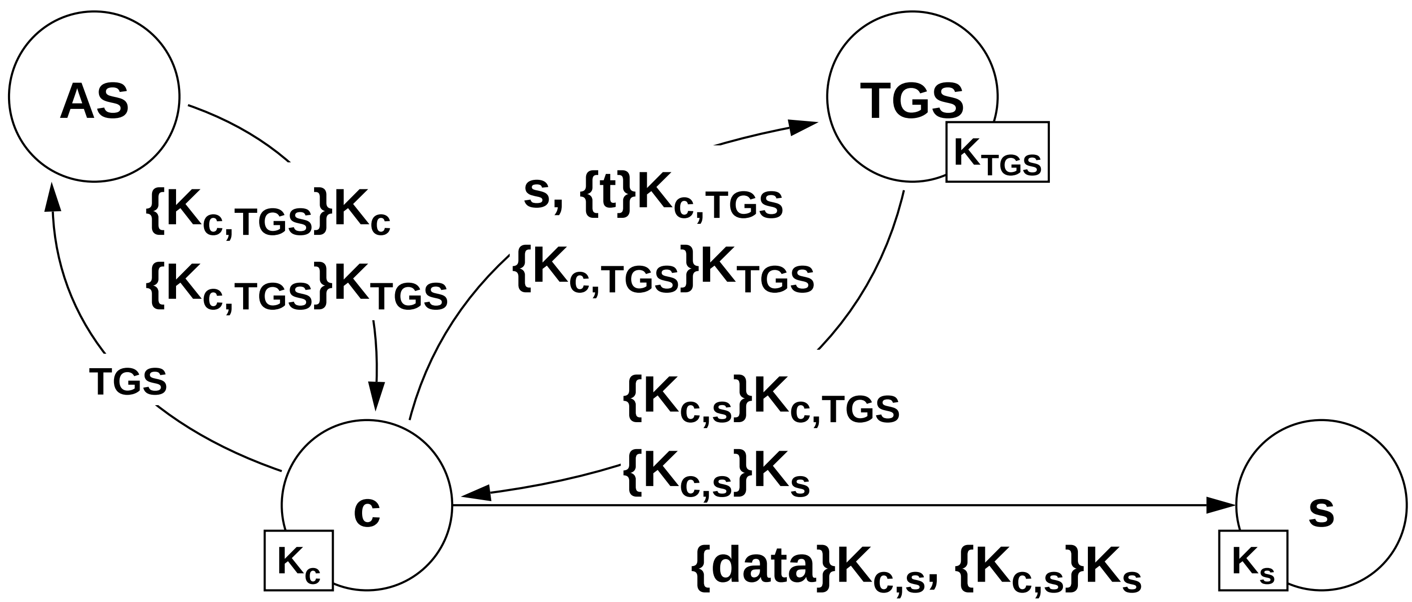


- TGS issues ticket for talking to the server s
- $K_{c,s}$ also has a short lifetime

TGS (Cont...)


AS
TGS
K_{TGS}
{$K_{c,TGS}$}K_c
{$K_{c,TGS}$}K_{TGS}
TGS
s, {t}$K_{c,TGS}$
{$K_{c,TGS}$}K_{TGS}
{$K_{c,s}$}$K_{c,TGS}$
{$K_{c,s}$}K_s
c
K_c
s
K_s
{data}$K_{c,s}$, {$K_{c,s}$}K_s

TGS (Cont...)



- K_c is only used *once* for talking to the AS *(single sign-on)*
  - may be twice if preauthentication is used
  - no need to talk to AS if c needs to talk to *another server*
  - for every server c would like to talk to, this would be done only a small number of times per day

Key Distribution Linked to Authentication

- Summary of techniques
  - be explicit about who you wish to talk to (name in request, check name in reply)
  - use nonce (check nonce value in reply)
  - use timestamp
  - use a separate authentication server (minimize use of K_c)
  - use preauthentication (to make sure no one else can generate the original request)
- It's all about knowing who has the keys
- We will revisit Kerberos when we discuss authentication

Public Key Distribution

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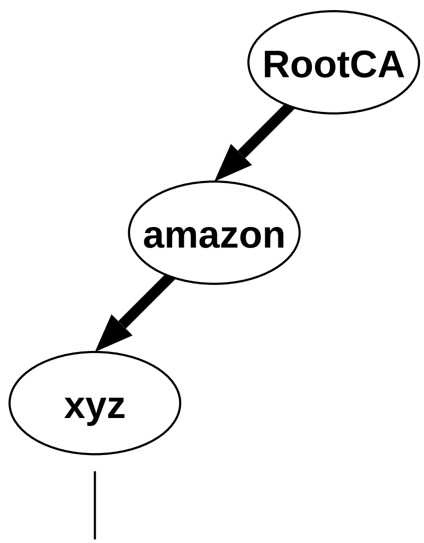
Public Key Distribution

- Public key can be public!
  - how does either side know who and what the key is for? private agreement? (not scalable)
    - who are you?
    - how do I know this public key belongs to amazon.com?
- Does this solve the key distribution problem?
  - no - while confidentiality is not required, *integrity* is
- Must *delegate trust*
  - why?
  - how?
  - trust VeriSign? trust IE, Netscape? who else are you trusting that you are not aware of? how many levels of delegation?

Certification Infrastructures

- Public keys represented by certificates
- Certificates signed by other certificates
  - user delegates trust to trusted certificates
  - certificate chains transfer trust up several links



Do you trust
a certificate
signed by amazon?

What Does A Public Key Certificate Look Like?

- **Example from OpenSSL:**
  - **include `CA.pl` in your path**

    ```
    set path=(~csci551b/openssl/ssl/misc $path)
    export PATH=~csci551b/openssl/ssl/misc:$PATH
    ```
  - **`CA.pl -newca`**
    - **creates:**

      `demoCA/private/cakey.pem`: ***CA private key***

      `demoCA/cacert.pem`: ***CA certificate (self-signed)***
  - **`CA.pl -newreq-nodes`**
    - **creates:**

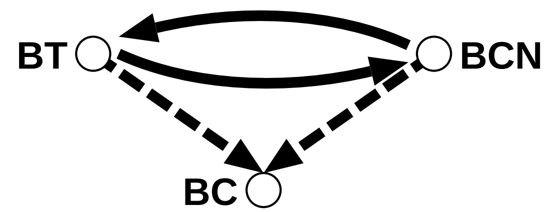
      `newreq.pem`: ***certificate request***

      `newkey.pem`: ***private key***
  - **`CA.pl -signreq`**
    - **creates a certificate: `newcert.pem`**

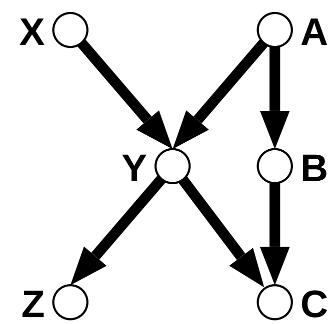
      copy of this is in `demoCA/newcerts`

Other Approaches

- PGP
  - "Web of Trust" (no CA)
  - can model as connected digraph of signers
  - signature has attributes (e.g., strength)



- X.500
  - hierarchical model: tree (or DAG?)
  - but X.509 certificates use ASN.1
  - X.509 uses MD5
    - in 2005, Lenstra and B. de Weger showed one can create a forged X.509 certificate



What Is ASN.1?

- Abstract Syntax Notation number One *(ASN.1)* is a standard that defines a formalism for the specification of *abstract data types* (standardized first in 1984, way before XML)
  - the notation provides a certain number of pre-defined basic types such as:
    - integers (INTEGER)
    - booleans (BOOLEAN)
    - character strings (IA5String, UniversalString...)
    - bit strings (BIT STRING)
  - and makes it possible to define constructed types such as:
    - structures (SEQUENCE)
    - lists (SEQUENCE OF)
    - choice between types (CHOICE)
  - lots of tools
    - http://asn1.elibel.tm.fr/

ASN.1

- What does ANS.1 grammer looks like?

```
Module-order DEFINITIONS AUTOMATIC TAGS ::=
BEGIN

Order ::= SEQUENCE {
    header  Order-header,
    items   SEQUENCE OF Order-line}
...
Order-line ::= SEQUENCE {
    item-code     Item-code,
    label         Label,
    quantity      Quantity,
    price         Cents }

Item-code ::= NumericString (SIZE (7))

Label ::= PrintableString (SIZE (1..30))

Quantity ::= CHOICE { unites       INTEGER,
                      millimetres  INTEGER,
                      milligrammes INTEGER }

Cents ::= INTEGER
...
END
```

Other Approaches (Cont...)

- SSH
  - user keys - out of band exchange
    - `ssh-keygen -b 1024 -t rsa`
    - install `~/.ssh/id_rsa.pub` in `~/.ssh/authorized_keys`
    - `ssh -i ~/.ssh/id_rsa ACCONT@HOST`
  - week assurance of server keys
    - was the same host you spoke with last time
- SET (Secured Electronic Transaction) has banks as CA's and common SET root
  - private key of the SET root CA is split and spread among child CA's
    - hierarchical
    - multiple roots
    - key splitting