Key Management and Distribution

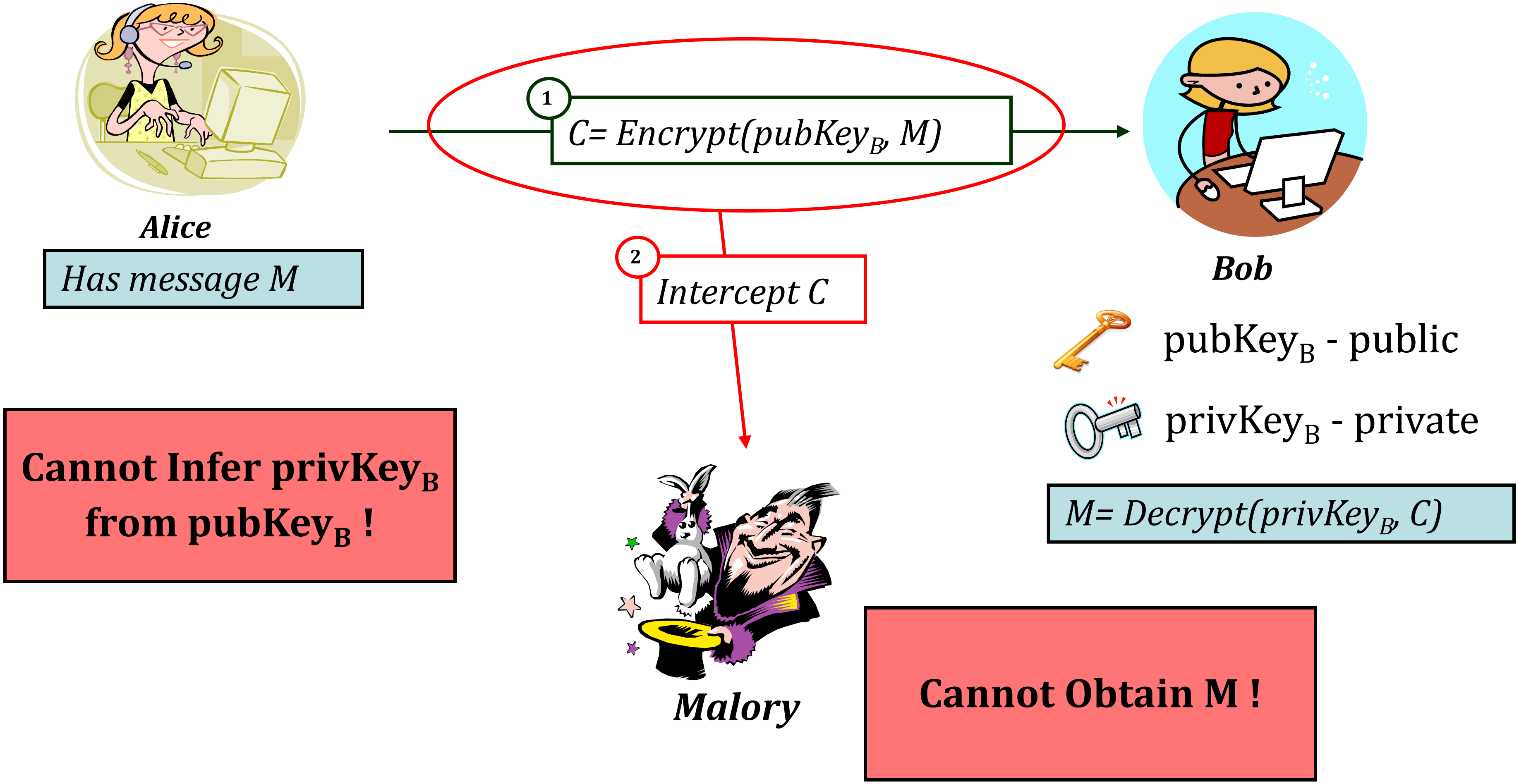
Class 5

Stallings: Ch 14

Announcement

- Homework 1 due today
- Still waiting for paper assignments

Key Distribution: The Problem



Alice

Has message M

1 *C= Encrypt(pubKey$_B$, M)*

2 *Intercept C*

Bob

pubKey$_B$ - public

privKey$_B$ - private

M= Decrypt(privKey$_B$, C)

Malory

Cannot Infer privKey$_B$ from pubKey$_B$!

Cannot Obtain M !

Key Distribution: Symmetric Key Scenario

- *Deliver a key to two parties that need to communicate securely*
    - Delivery needs to be secure: only the two parties have access to the key

Symmetric Key Scenario

- Two parties A and B
- Symmetric encryption: most efficient way to send encrypted data
- Both parties need to share a secret
- For N parties, this means N(N-1)/2 secrets !
  - Not all are needed

- How to *securely* and *efficiently* establish pairwise secrets

How To Distribute Keys

- Session key distribution with symmetric crypto
- Session key distribution with public key crypto
- Distribution of authentic public keys
- X.509 certificates

Symmetric Crypto Notations

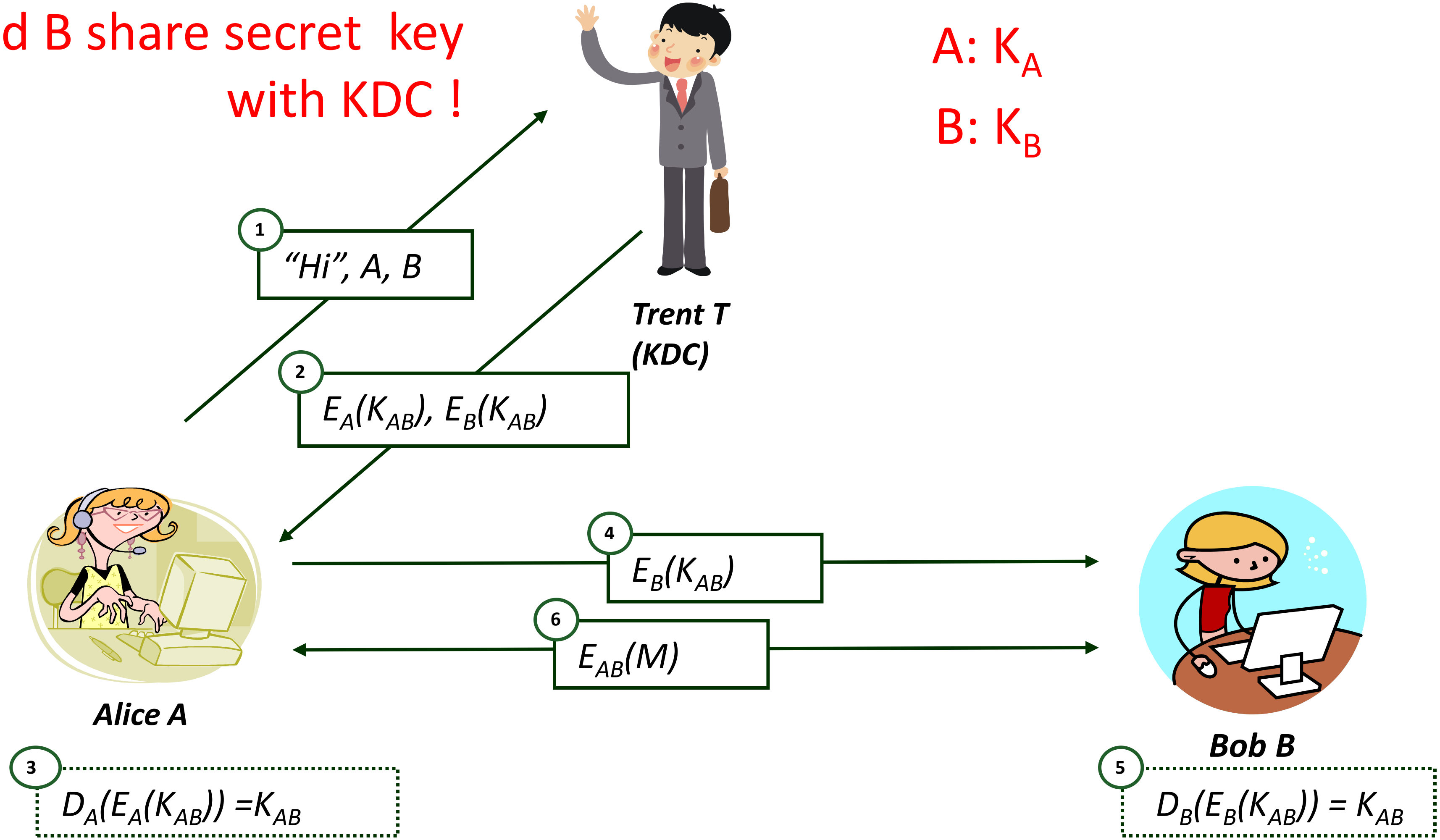
- Alice shares key K_A with KDC
    - Encryption: $E_A(M)$ = $E(K_A, M) = C$
    - Decryption: $D_A(M)$ = $D(K_A, C)$

Symmetric Key Based Distribution

A and B share secret key with KDC !

A: K_A

B: K_B



Trent T (KDC)

Alice A

Bob B

1 “Hi”, A, B

2 $E_A(K_{AB}), E_B(K_{AB})$

3 $D_A(E_A(K_{AB})) = K_{AB}$

4 $E_B(K_{AB})$

5 $D_B(E_B(K_{AB})) = K_{AB}$

6 $E_{AB}(M)$

Key Distribution Problems

- Trent (the KDC) is absolutely trusted
  - If Malory corrupts KDC, all is gone
  - Malory can read all user communication
  - *Why ?*
- Trent is a bottleneck
  - *If Trent fails, the entire system is disrupted*

How To Distribute Keys

- Session key distribution with symmetric crypto
- Session key distribution with public key crypto
- Distribution of authentic public keys
- X.509 certificates

Public Key Based Distribution

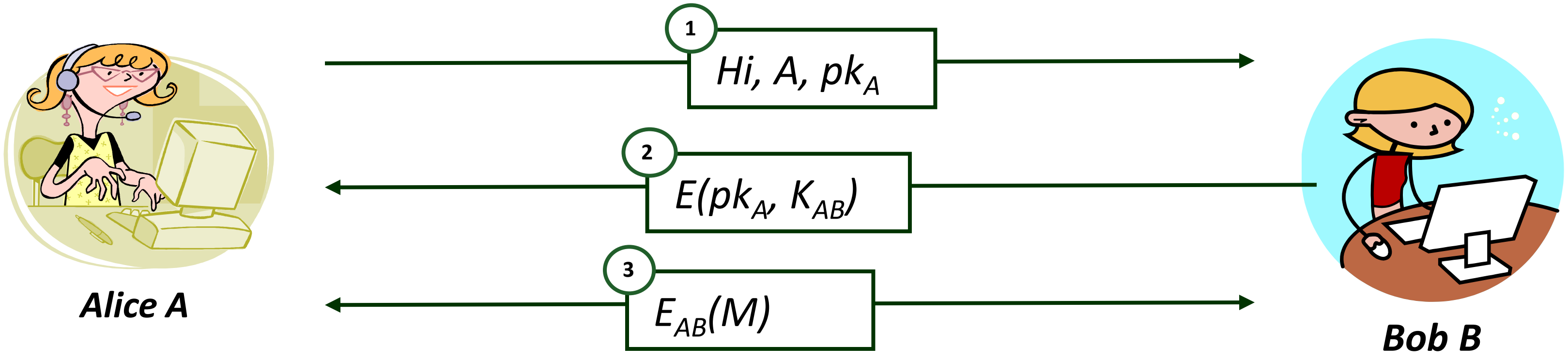
- A and B use public key crypto
  - To agree on a session key
  - Session key is used to encrypt communications
- *How do A and B know each other’s public keys?*

Public Key Crypto Notations

- Alice has key pair (pk_A, pr_A)
  - pk_A is the public key
  - pr_A is the private key
- Encryption/Decryption
  - C = E_A(Msg) = E(pk_A, Msg) – anyone can do
  - D_A(C) = D(pr_A, C) – only Alice can do this

KD with Public Key – Direct Exchange

Merkle proposed this very simple scheme



1 Hi, A, pk_A

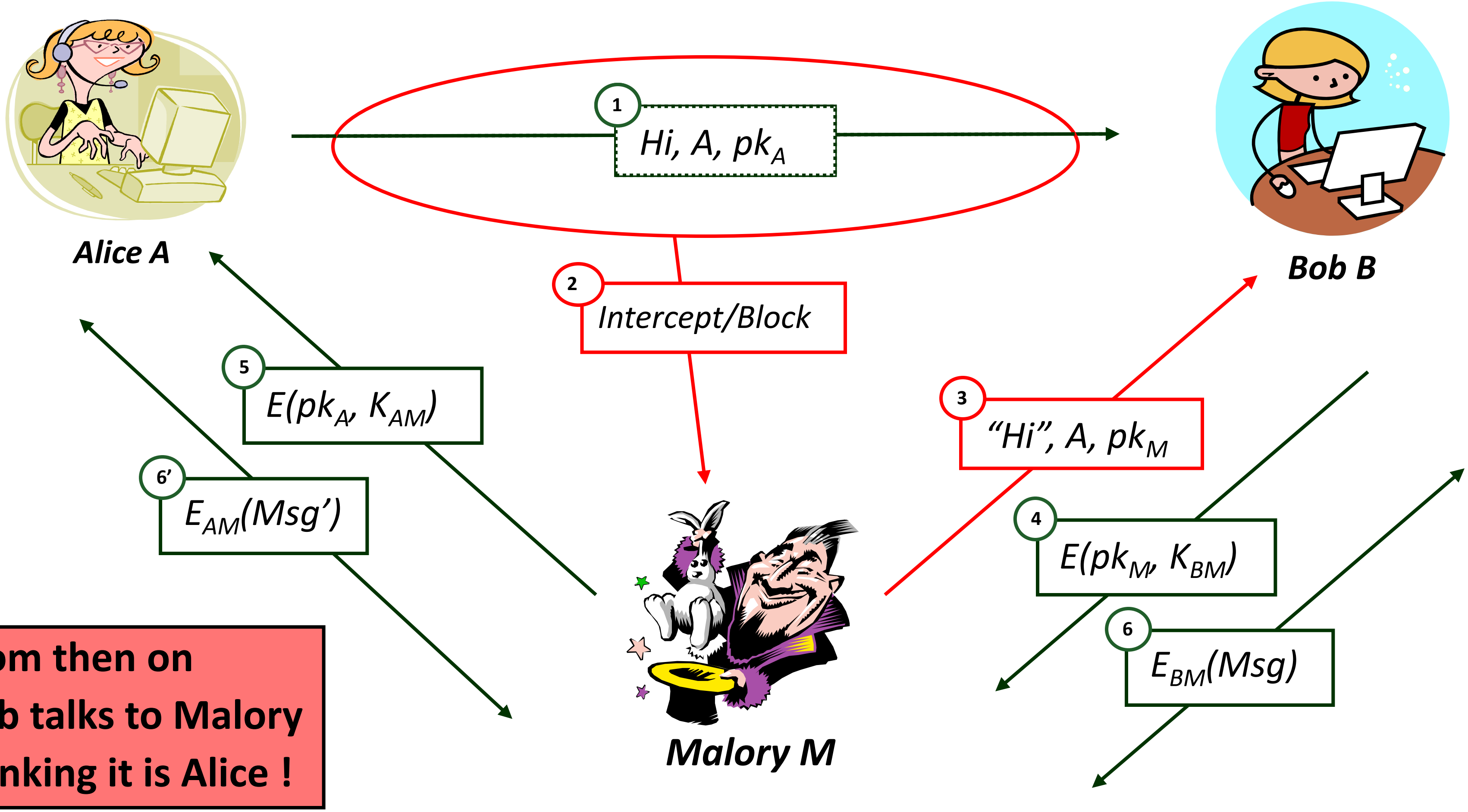
2 $E(pk_A, K_{AB})$

3 $E_{AB}(M)$

Alice A

Bob B

Man-in-the-Middle Attack



Alice A

Bob B

Malory M

1 *Hi, A, pk_A*

2 *Intercept/Block*

3 *“Hi”, A, pk_M*

4 *$E(pk_M, K_{BM})$*

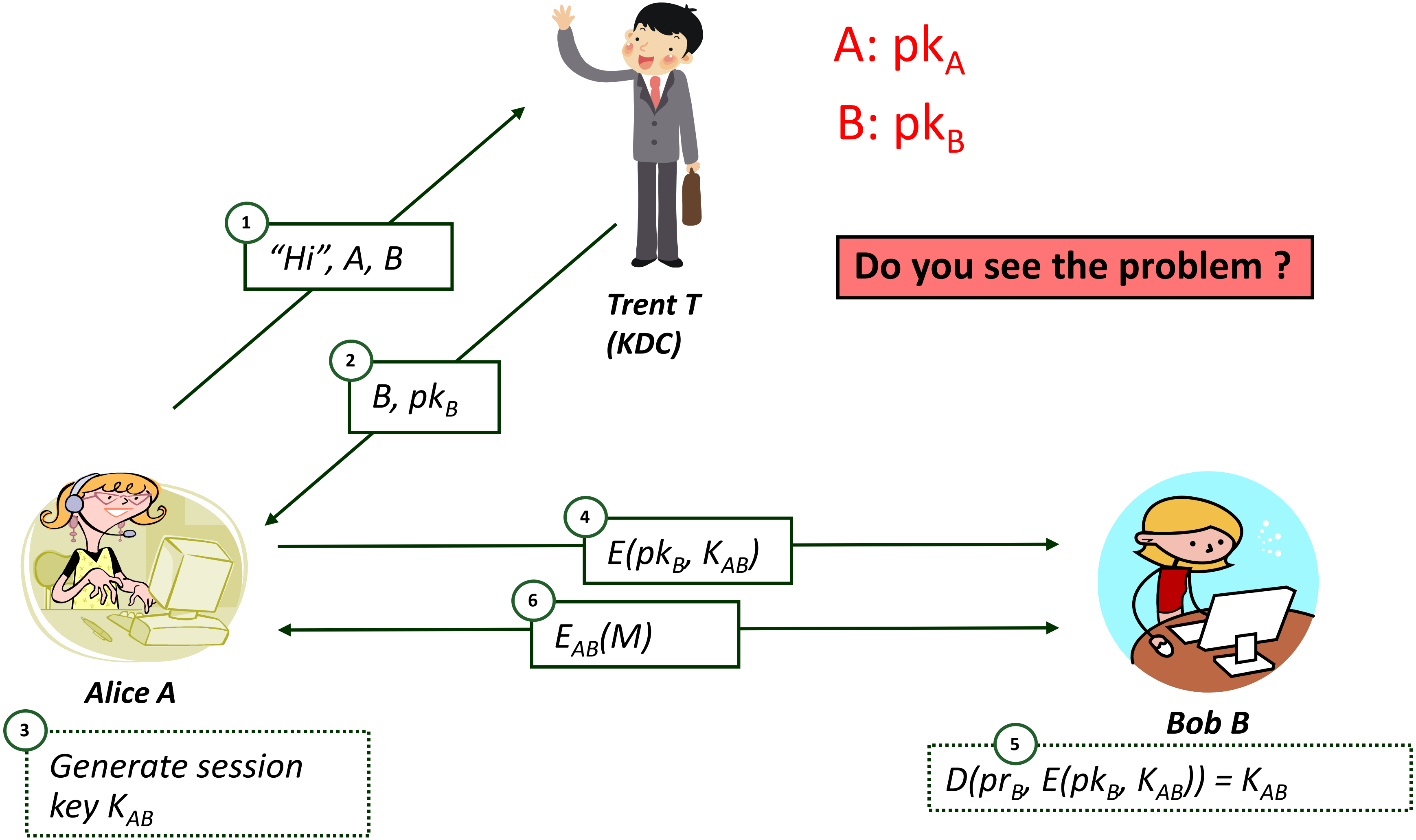
5 *$E(pk_A, K_{AM})$*

6 *$E_{BM}(Msg)$*

6’ *$E_{AM}(Msg’)$*

From then on Bob talks to Malory thinking it is Alice !

Key Distribution with Public Key and KDC



A: pk_A

B: pk_B

Do you see the problem ?

Trent T (KDC)

1 *"Hi", A, B*

2 *B, pk_B*

Alice A

3 *Generate session key K_{AB}*

4 *$E(pk_B, K_{AB})$*

Bob B

5 *$D(pr_B, E(pk_B, K_{AB})) = K_{AB}$*

6 *$E_{AB}(M)$*

How To Distribute Keys

- Session key distribution with symmetric crypto
- Session key distribution with public key crypto
- Distribution of authentic public keys
- X.509 certificates

Distribution of Public Keys !

- How are they distributed in the first place ?
  - Remember Merkle’s solution
  - … and the Man-in-the-Middle Attack
- *Need an authentic way to distribute keys !*
- Alternatives
  - Public announcement
  - Publicly available directory
  - Public-key authority
  - Public-key certificates

Public Announcement

- Similar to Merkle’s first step …
- Users distribute public keys to recipients or broadcast to community at large
  - Append keys to email messages
  - Post to news groups or email list
- *Major weakness is man-in-the-middle*
  - Anyone can create a key claiming to be someone else and broadcast it
  - Until forgery is discovered can masquerade as claimed user

Publicly Available Directory

- Register keys with a public directory
- Directory contains {name,public-key} entries
- Participants register securely with directory
  - In person or using secure authentication
- Participants can replace key at any time
- Directory can be accessed electronically
  - Needs secure, authentic communication to directory
- *Vulnerable to tampering or forgery*

Public Key Authority

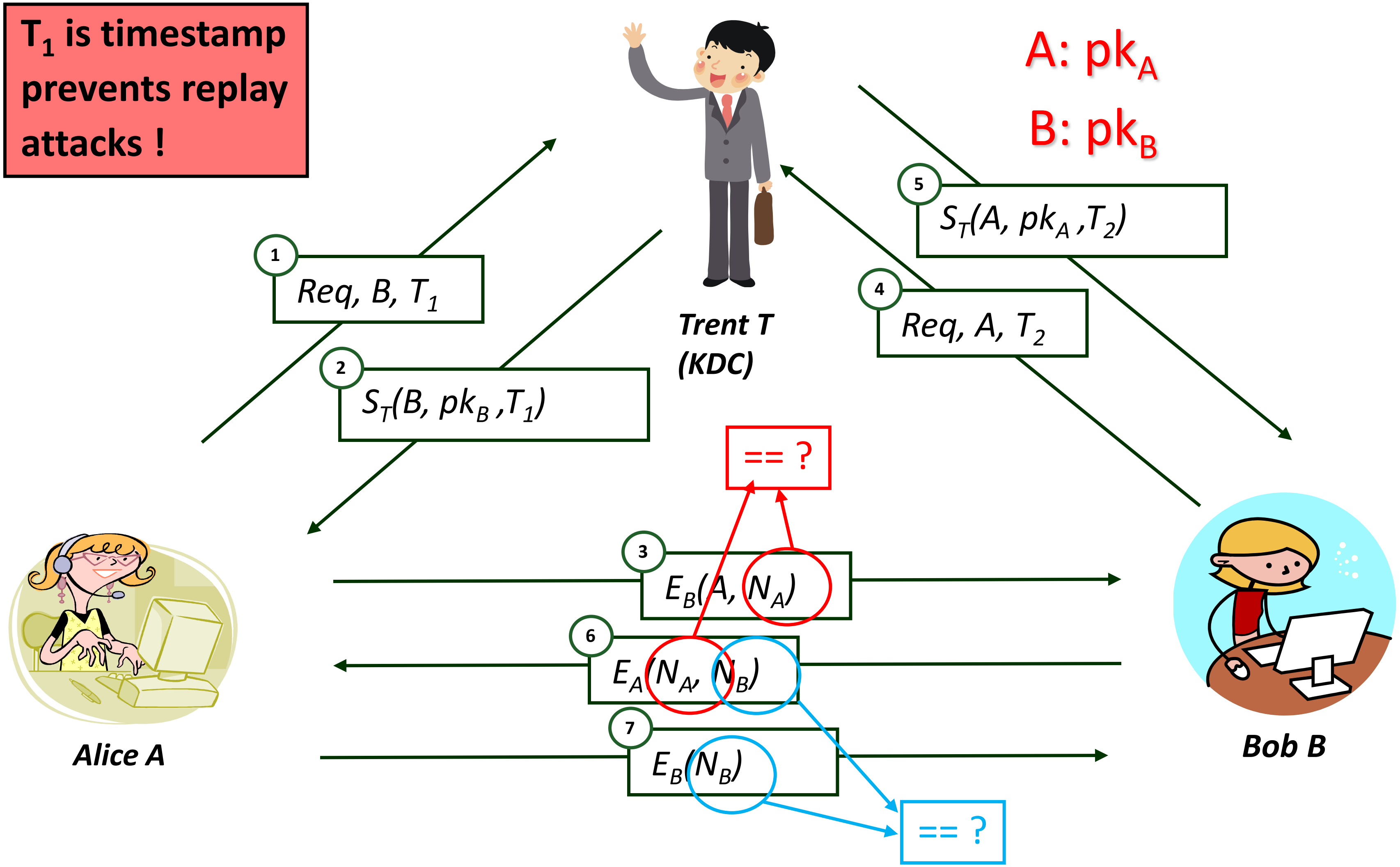
- Has properties of directory *plus*
- *Requires users to know public key of authority*
- Users interact with directory to obtain any desired public key securely
  - Requires real-time access to directory when keys are needed
- *May be vulnerable to tampering*

Public Key Crypto Notations

- Alice has key pair (pk_A, pr_A)
  - pk_A is the public key
  - pr_A is the private key
- Encryption/Decryption
  - $E_A(M) = E(pk_A,M)$ – anyone can do this
  - $D_A(M) = D(pr_A,M)$ – only Alice can do this
- Signature/Verification
  - $S_A(M)$: sign message M with private key of A
  - $V_A(M, S)$: verify that S is a signature for M
    - Uses A’s public key

Public Key Authority (Needham-Schroeder with Public Keys)

T_1 is timestamp prevents replay attacks !



A: pk_A

B: pk_B

1 Req, B, T_1

2 $S_T(B, pk_B, T_1)$

3 $E_B(A, N_A)$

4 Req, A, T_2

5 $S_T(A, pk_A, T_2)$

6 $E_A(N_A, N_B)$

7 $E_B(N_B)$

== ?

== ?

Public Key Authority Use (cont'd)

- Why do we need T's signature ?
  - A and B can be sure of the other's public key
- Why do we need steps 6 and 7 ?
  - A makes sure B knows its private key
  - Makes sure Mallory cannot impersonate B
  - … and vice-versa

How To Distribute Keys

- Session key distribution with symmetric crypto
- Session key distribution with public key crypto
- Distribution of authentic public keys
- X.509 certificates

Public Key Certificates

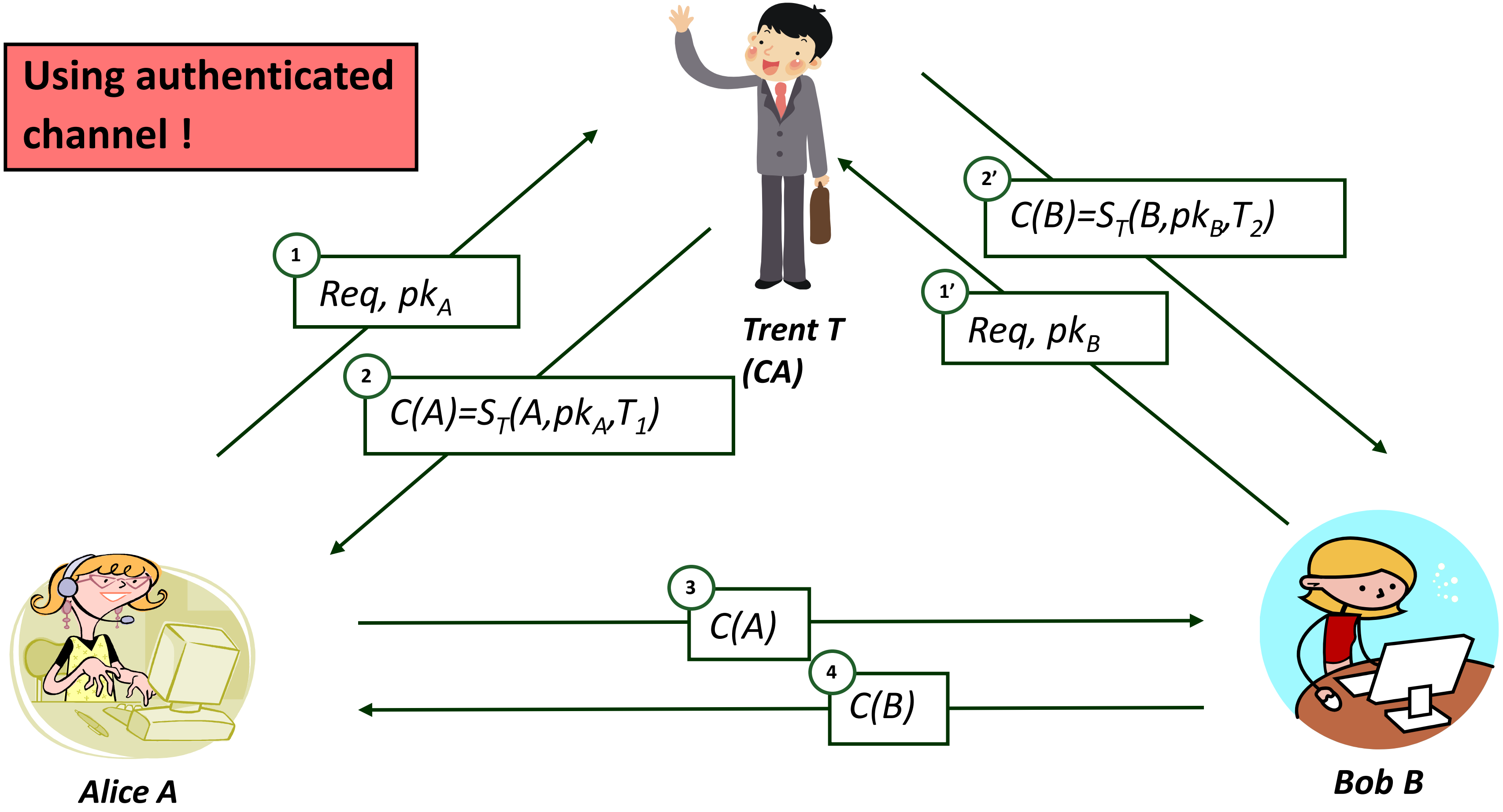
- Allow key exchange without real-time access to public-key authority
- Bind **identity** to **public key**
  - Plus other info: period of validity, rights of use etc
- All contents **signed** by a trusted Public-Key or Certificate Authority (CA)
  - Can be verified by anyone who knows the public-key authority's public-key

Certificate Requirements

- Anyone can read the name and public key from a certificate
- Only the CA can *create* and *update* certificates
- Anyone can *verify the validity* of the certificate

How are Certificates Used ?

Using authenticated channel !



1 Req, pk_A

2 $C(A)=S_T(A,pk_A,T_1)$

Trent T (CA)

1’ Req, pk_B

2’ $C(B)=S_T(B,pk_B,T_2)$

3 $C(A)$

4 $C(B)$

Alice A

Bob B

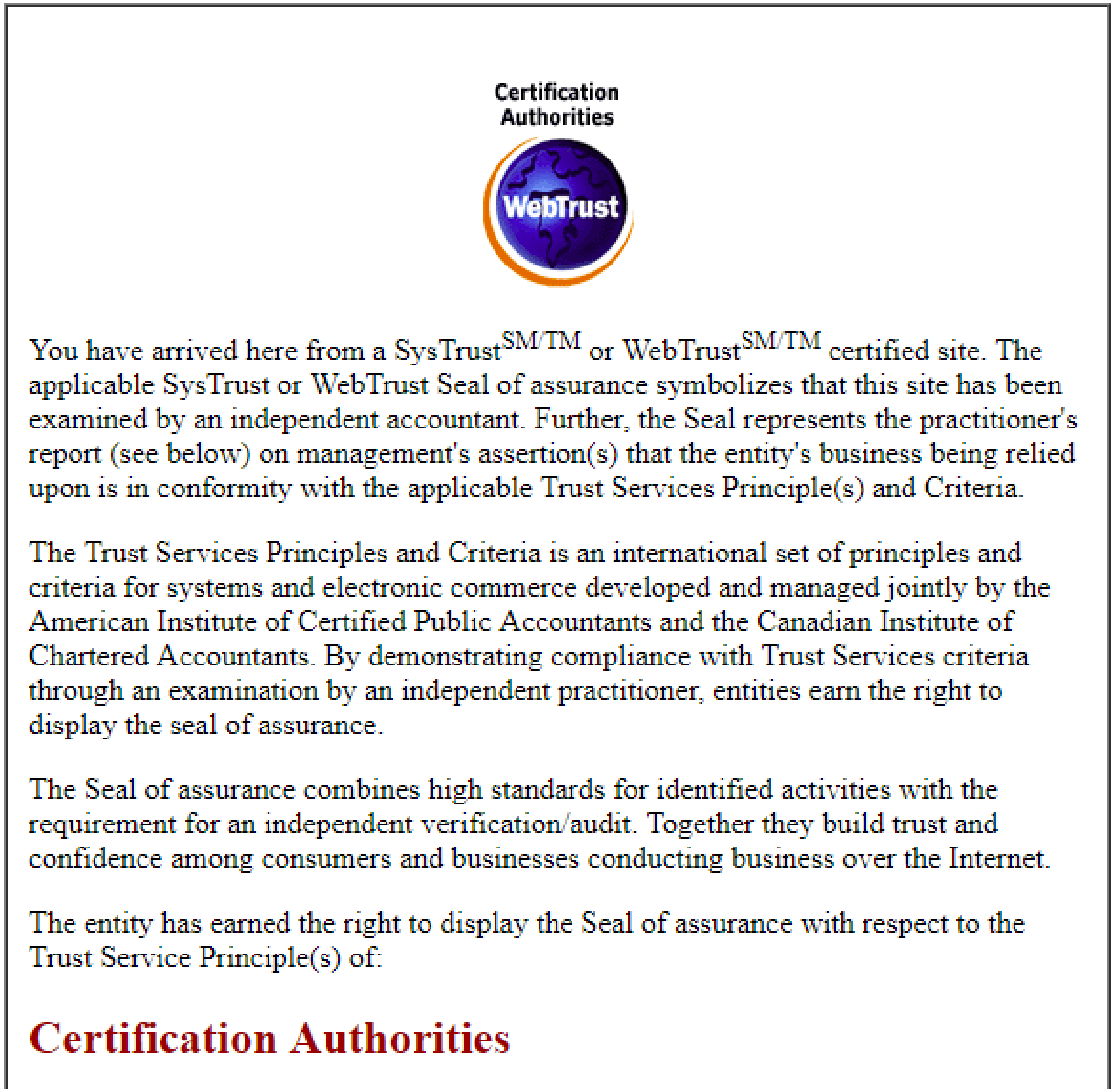
How are Certificates Used ? (cont'd)

- Certificates *issued*
  - Over authenticated channels
  - In person
- Certificates are re-issued infrequently
  - Steps 1 and 2 are done once
- Certificates contain timestamp and validity period
  - User can verify certificate validity
- Example CAs: Symantec (VeriSign), Comodo, GoDaddy

Symantec (former VeriSign)

- For websites
- Examines
  - Traditional documents like articles of incorporation and business licenses
  - Digital verification of each site operated by the organization

WebTrust https://cert.webtrust.org



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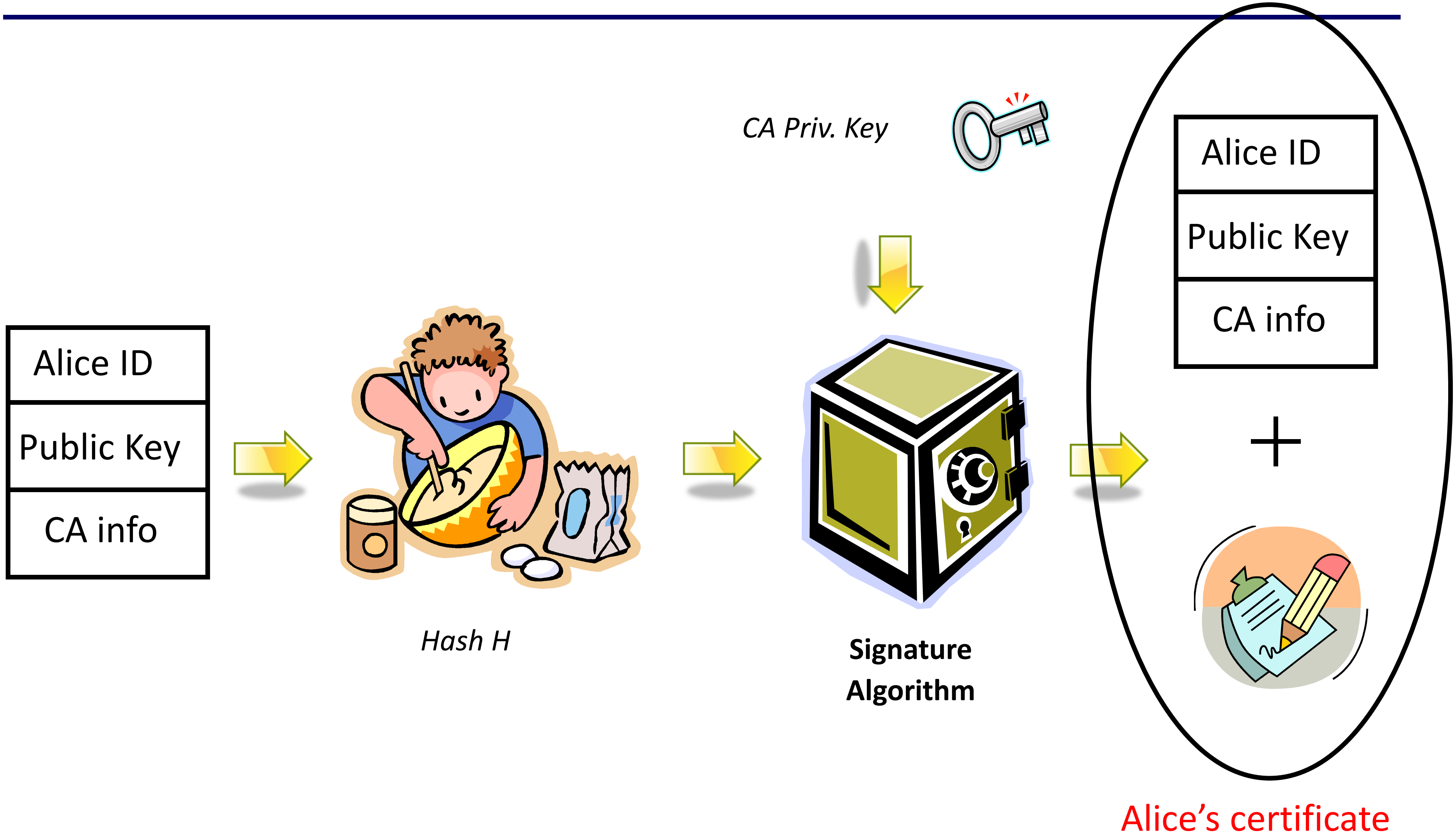
The entity has earned the right to display the Seal of assurance with respect to the Trust Service Principle(s) of:

Certification Authorities

X.509 Certificates

- Part of CCITT X.500 directory service standards
  - Distributed servers maintaining user info database
- *Defines framework for authentication services*
  - Directory may store public-key certificates
  - Public key of user signed by certification authority
- Defines authentication protocols
- Uses public-key crypto & digital signatures
  - Algorithms not standardised, but RSA recommended
- X.509 certificates are widely used
  - have 3 versions

X.509 Certificate Generation



Alice ID

Public Key

CA info

Hash H

CA Priv. Key

Signature Algorithm

Alice ID

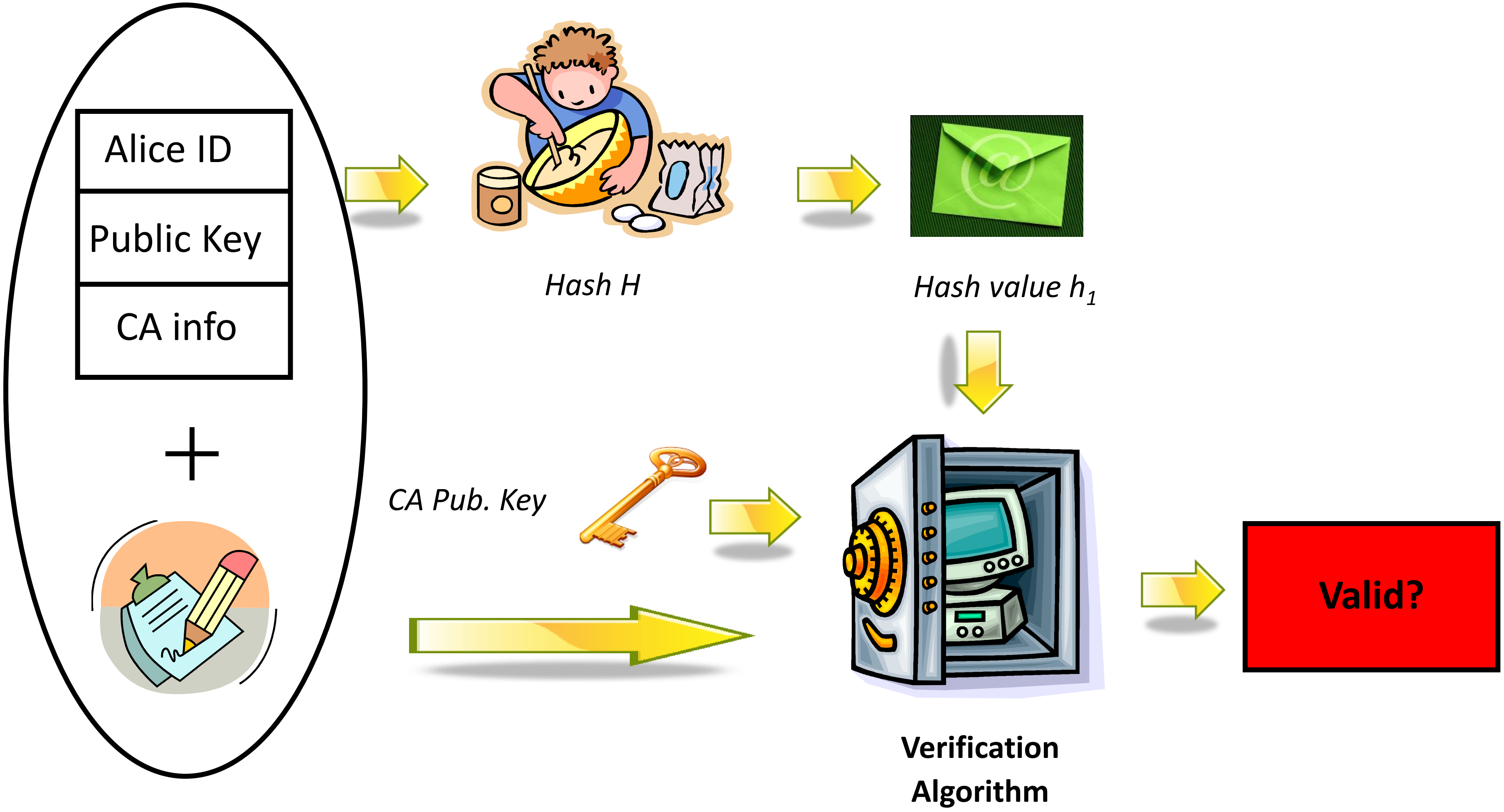
Public Key

CA info

+

Alice's certificate

X.509 Certificate Verification



Alice ID

Public Key

CA info

+

Hash H

Hash value h_1

CA Pub. Key

Valid?

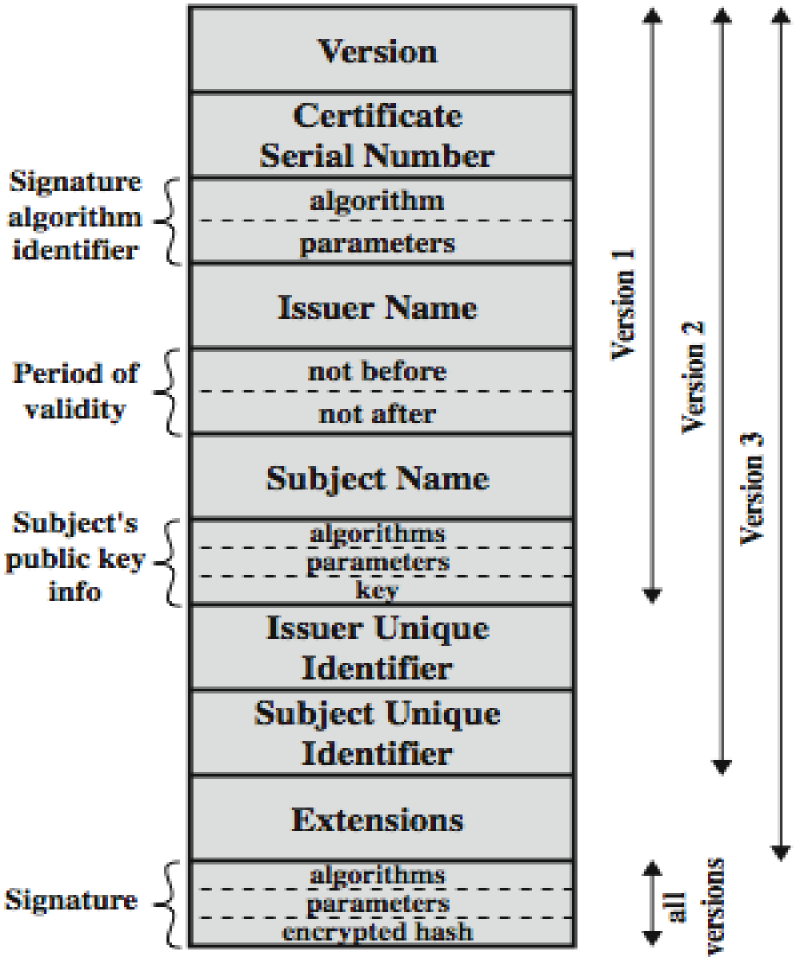
Verification Algorithm

Alice’s certificate

X.509 Certificate Format

- Issued by a Certification Authority (CA), containing:
  - version (1, 2, or 3)
  - serial number (unique within CA) identifying certificate
  - signature algorithm identifier
  - issuer X.500 name
  - **period of validity (from - to dates)**
  - subject X.500 name (name of owner)
  - subject public-key info (algorithm, parameters, key)
  - issuer unique identifier (v2+)
  - subject unique identifier (v2+)
  - extension fields (v3)
  - **signature (of hash of all fields in certificate)**
- Notation: C_{CA}(A) is certificate for A signed by CA

X.509 Certificate Format (cont'd)



(a) X.509 Certificate

From Stallings book

X.509 Version 3

- Additional information may be needed in a certificate
  - E-mail/URL, policy details, usage constraints
- Hard to explicitly name new fields
  - Backward compatibility issues
- *Define a general extension method*
  - Extension identifier
  - Criticality indicator
  - Extension value

Obtaining a Certificate

- Any user with access to CA can get any certificate from it
- Only the CA can modify a certificate
- Certificates can be placed in a public directory
- *Certificates cannot be forged*

Certificate Revocation

- Certificates have a period of validity
- *May need to be revoked before expiry:*

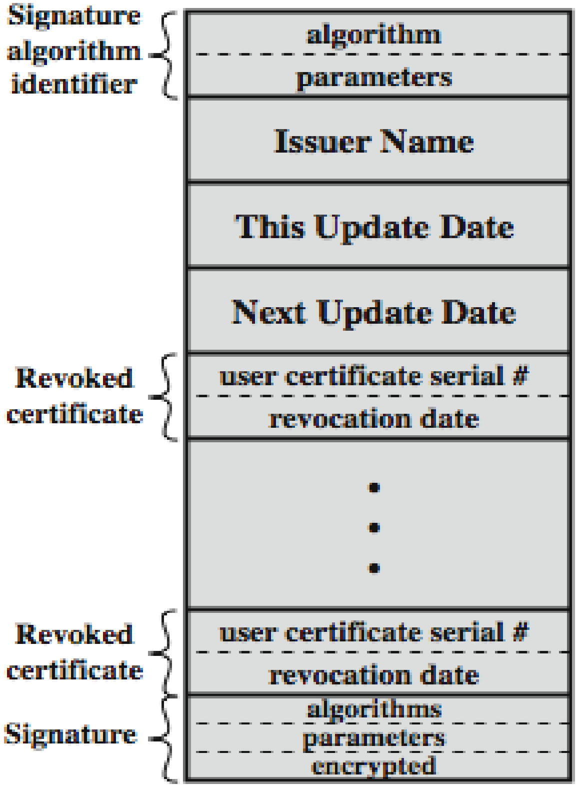
1. User's private key is compromised
2. User is no longer certified by this CA
3. CA's certificate is compromised
4. User behaves badly

- CA maintains list of revoked certificates
  - Certificate Revocation List (CRL)
- Users should check certificates with CA’s CRL

Certificate Revocation (cont'd)

- When Alice obtains Bob's certificate
  - Contact CA
  - Check that certificate is not revoked (in CRL) !

- CA needs to maintain a certificate in CRL until certificate expires



(b) Certificate Revocation List

From Stallings book

Certificate Revocation Problem

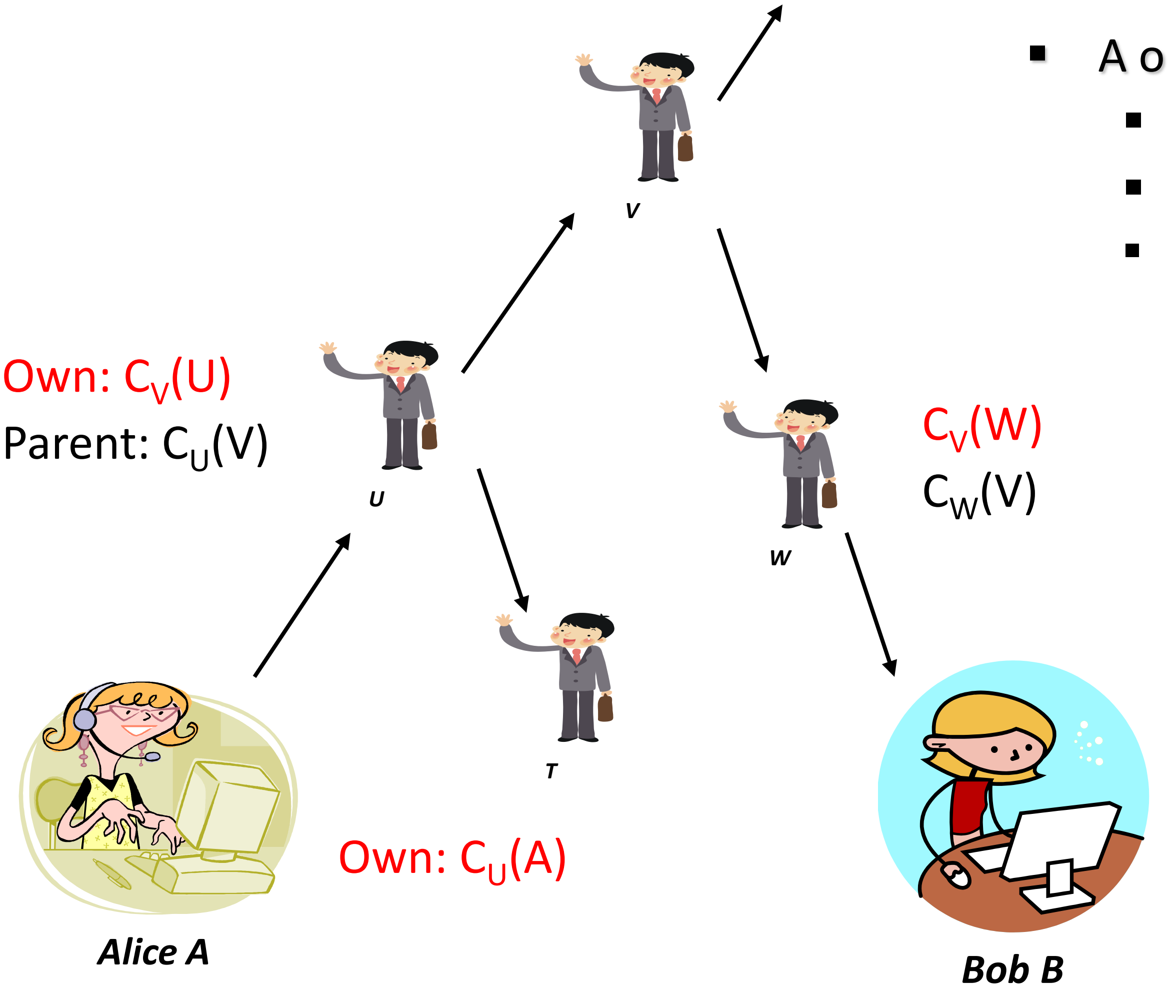
- Alice does something bad at time T_1
- CA finds out and revokes A’s certificate at T_2
  - Place A certificate into CRL
- Alice can continue to misbehave and be authenticated between T_1 and T_2 !

CA Hierarchy

- What if A and B do not share a CA ?
- Solution: CA's must form a hierarchy
- Use certificates linking members of hierarchy to validate other CA's
  - Each CA has certificates for itself (from parent CA) and for parent (backward)
- Each client trusts parents certificates

CA Hierarchy Example

- A obtains B's certificate
  - $C_U(V)$
  - $C_V(W)$
  - $C_W(B)$



Own: $C_V(U)$

Parent: $C_U(V)$

$C_V(W)$

$C_W(V)$

Own: $C_U(A)$

Own: $C_W(B)$

Certificate Types

- **Root certificate (Trust anchor)**
  - Self-signed certificate used to sign other certificates
  - E.g., Google Trust Services (https://pki.goog/)
- **Intermediate certificate**
  - Used to sign other certificates
  - Must be signed by intermediate or root certificate
- **End-entity or leaf certificate**
  - Cannot be used to sign other certificates
  - TLS/SSL server and client certificates
  - Email certificates